COMPLEXITIES IN DECISION-MAKING BY NATURAL RESOURCE MANAGERS: A STUDY OF FIRE SUPPRESSION DECISIONS IN THE NORTHERN ROCKIES

By

Molly C. Daniels

A thesis submitted in partial fulfillment of

the requirements for the degree of

Master of Science

(Environment and Resources)

at the

UNIVERSITY OF WISCONSIN-MADISON

2019

ABSTRACT

This thesis aims to identify key management, socioeconomic, environmental and fire characteristics impacting managers' suppression decisions during fire incidents in the Northern Rocky Mountains. I test the strengths and nature of relationships between suppression decisions and these variables using qualitative and quantitative methods. Specifically, I develop regression analyses of fire incident reports from 374 fires between 2008 and 2013 and interview fire managers from the region. Full suppression was associated with management variables such as non-federal land jurisdiction, more national incident management teams, and earlier report dates within the fire season, along with higher housing density, human-caused ignitions, low to moderate terrain, light vegetation cover, and greater fire size. Analysis of interviews with eight fire managers provides decision-making context for these variables within the study period and outlooks for future manager decision space. Future efforts to allow less-than-full suppression should examine the complex management context in addition to the biophysical context of fire response.

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Adena Rissman, for her guidance, patience, and wisdom. Without her, this thesis would not be possible. I would also like to thank the rest of my committee, Dr. Rob Beattie and Dr. Monica Turner, whose advice and support were instrumental in my success. I would like to extend my gratitude to Karen Thompson, at US Forest Service, for providing instrumental data upon which my findings are based. Thanks to Kristin Braziunas, who has guided me academically and inspired me personally for the last several years.

Thanks go to Jim Miller, Nathan Schulfer, Dr. Jen Hauxwell, Michael Liou, Josh Kinsey, Analisa Silva, Christine Anhalt-Depies, Alex Kazer, Tierney Bosci, and Kaycie Waters – for your time, effort, and encouragement. My love and thanks to my family and friends for their encouragement and understanding; especially Nate, for all those dinners made while I feverishly - and selfishly - worked on this. Although words cannot fulfill the gratitude owed, from the bottom of my heart, I thank you.

Funding for this project was provided by the Joint Fire Science Program (JFSP) (16-3-01). The JFSP has financially supported hundreds and hundreds of students and researchers across the country, and I am proud to be among their numbers.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

This thesis investigates the roles of management, socioeconomic, environmental, and fire behavior factors in the decision-making of fire managers in the Northern US Rocky Mountains. This analysis is rooted in an understanding of management decision-making within complex social-ecological systems. It takes an interdisciplinary approach to linking environmental, socioeconomic, and managerial settings through mixed-methods empirical research. My multifaceted background provides the necessary integrative approach to the study of resource management within disturbance regimes. By applying an interdisciplinary lens to the investigation, I connect fire incident management in the Northern Rockies to decision-making impacting management of natural resources more broadly. This complex landscape, both in terms of environmental characteristics and management settings, provides advantageous conditions for social-ecological research.

Many factors impact fire manager decisions, including weather, vegetation, remoteness, and topography (Canton-Thompson et al. 2008), and social and psychological drivers such as risk tolerance, agency attitudes and beliefs, and trust (Thompson 2014). Socioeconomic, environmental, and fire behavior variables also influence the outcomes – such as financial – of suppression decisions during fire incidents (Gude et al. 2013). The existing literature has explored similar factors to those in my study, such as US Census Data and distance to roads/rails (Cardille, Ventura, & Turner 2001), as well as land-cover impacts to fire behavior (Sturtevant & Cleland 2007), in other geographic regions.

By looking at how management factors, such as the level of the incident management team assigned to the fire, and socioeconomic factors, such as home value, are associated with suppression decisions, this research builds upon the foundational understanding of how these variables can impact fire behavior and outcomes.

I look at how management factors, such as the level of the incident management team assigned to the fire, and socioeconomic factors, such as wildland-urban interface (WUI) class and home values, influence suppression decisions (in addition to landscape factors). Specifically, I ask: what landscape, anthropogenic, and management factors were associated with fire suppression types – full suppression, point-zone, confine and contain, and maintain and monitor – reported on fires occurring between 2008 and 2013? If suppression method changed during the incident, what factors were associated with those changes (see Appendix B)? And what changes or contexts will allow incident commanders (ICs) to feel more enabled to select less-than-full suppression methods in the future (see Appendix C)? The goals of my research are to examine management, socioeconomic, environmental, and fire behavior factors that have impacted suppression decisions in managing fires in the northern Rocky Mountains, and to identify changes that might assist agencies in fire policy development and ICs in selecting less-than-full suppression approaches when appropriate.

Research methods include interviews, spatial analysis, and generalized additive mixed model regression analyses. A mixed methods approach provides more context surrounding the decisions made during fire incidents and enhances the validity of inferences drawn from regression estimates of the factors that influence suppression decisions.

The northern US Rocky Mountains is a data-rich ecoregion that includes Greater Yellowstone and the Crown of the Continent and is ideal for academic study. Dominant forest types include species with varied fire-related traits, including thick-barked fire resisters (e.g., Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*)), resprouters (e.g., aspen (*Populus tremuloides*)), seed bankers (lodgepole pine (*Pinus contorta*)) and fire-sensitive shade tolerants (e.g., Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*)) (Baker 2003). Historical fire regimes range from infrequent, stand-replacing regimes in higher elevation and mesic forests to mixed-severity regimes in lower montane forests. The frequency of large fires and annual area burned have increased dramatically since the mid-1980s (Westerling 2016; Westerling et al. 2006). Land ownership and use are varied, and a wide range of management contexts (including extensive WUI) on public and private lands is represented.

Background

In the late 19th and early 20th centuries, fires in the US were suppressed at all costs; simultaneously, many forests were logged extensively and opened up for public grazing (Steelman & McCaffrey 2011; Westerling et al. 2006). This aggressive suppression policy outlook is exemplified by the 10 AM policy codified in 1935, which plainly and forcibly called for suppression of any fire by 10 a.m. the day after ignition (Donovan & Brown 2007).

Later in the 20th century, US fire policy began shifting away from full suppression, but the practices on the ground didn't transition for several decades (Steelman & McCaffrey 2011). This shifted management away from mandated full suppression, beginning in the Northern Rockies in the 1960s, but the policies were not equipped for hotter, drier conditions. This sparked the surprise over the 1988 Yellowstone fires (Turner et al. 1994). The history of fire suppression emphasizing control and minimizing fire on the landscape allowed for a straightforward set of policies, policies which limited the ambiguity of the policies' application to the work of forest and fire managers on the ground. However, fire suppression costs have grown exponentially since early fire policy (Canton-Thompson et al. 2008; Ingalsbee & Raja 2015), and the context surrounding fire has grown in complexity due to the expansion of the WUI, the inclusion of protecting values at risk in forest management plans (including sensitive wildlife habitat or ecologically and economically valuable headwaters), and more (Radeloff et al. 2018; Thompson et al. 2000).

There has been growing recognition that fire suppression may interrupt ecological processes with negative future impacts (Spies et al. 2017). Additionally, scientists and forest managers have acknowledged the benefits of fire even in the context of multiple-use areas, such as timber harvest areas (Lotan 1979; Thompson et al. 2000). Using less-than-full suppression allows agencies to balance resources across the US where other regions may be in more dire need of resources. Less-than-full suppression allows the incident commander (IC) to adapt to fire behavior and landscape conditions as opposed to delaying fire on the landscape until they are forced into a dangerous situation with no easy resolution. Risks of less-than-full suppression may seem obvious, such as the potential for the fire to leave the "box" fire managers set as an acceptable area for the fire. Outside of this box may be values at risk (i.e. private homes, sensitive wildlife habitat). Less-than-full suppression also risks the potential for the fire to need an aggressive management approach later on, when the fire is much larger, requiring significantly more resources, thus increasing incident costs and increasing negative perceptions of fire management in surrounding communities.

Decision Context

Fire incidents are assigned an IC based on the first agency personnel on site until command is transferred to the lead agency's assigned IC or until the incident is no longer active (Buck, Trainor, & Aguirre 2006). The IC is responsible for establishing an Incident Command Post, assigning roles to necessary Incident Command System (ICS) positions within the incident, determining the suppression method(s), requesting equipment, and more. The IC has authority granted to him or her through the Delegation of Authority. The ICS and its components are required for federal funding for emergency events through NIMS (Buck et al. 2006).

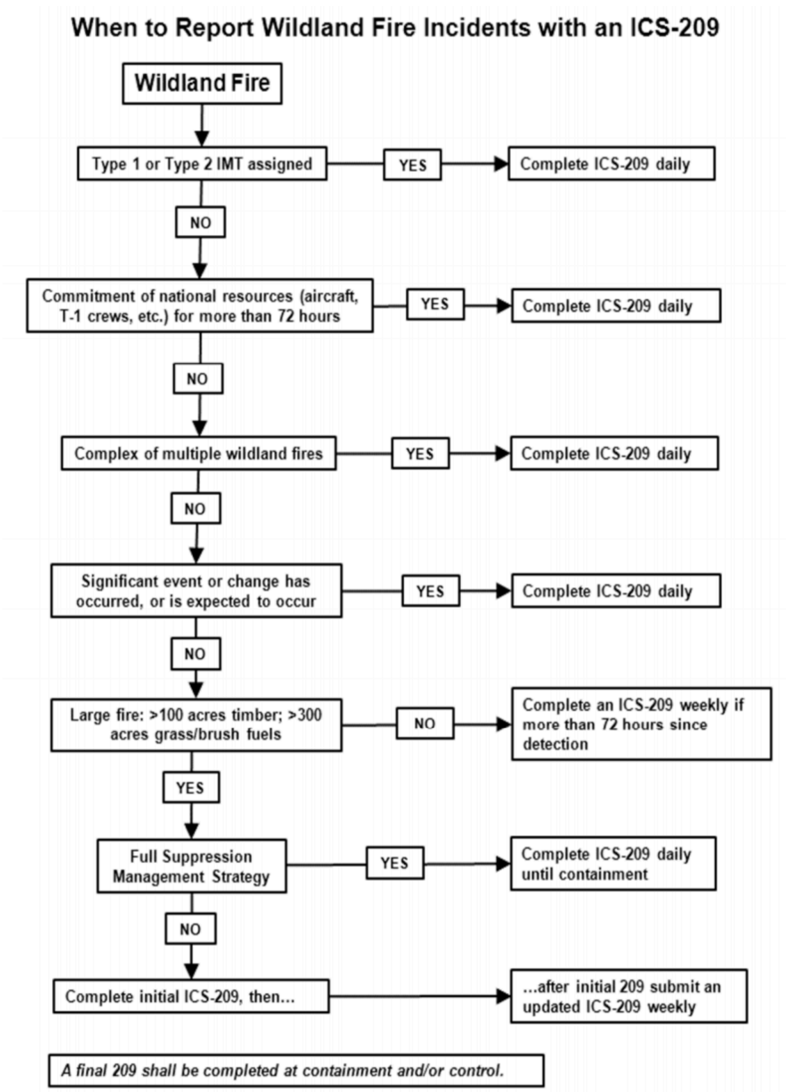

Figure 2. Flowchart by which ICs complete 209s. Data source: Geographic Agency Coordinating Centers' National Interagency Fire Center

The system standardizes the planning, implementation, and reporting of fire management in the US. This includes the use of 209s, otherwise known as situation reports, which are used for emergency incidents managed through ICS. These can include floods, fires, earthquakes, hazardous materials cleanup, and other disasters (Moynihan

2009). The frequency and extent to which ICs complete 209s depends on several factors, primarily the fire's duration and complexity (see Figure 2) (Hannestad 2005). ICS also standardizes training and qualifications for IC and Incident Management Team (IMT) personnel. IC levels range from an IC type 5 to an IC type 1, from least amount of training and most local to the highest trained, national-level ICs. Type 1 ICs frequently travel across the country and internationally, as requested by the lead agency of a fire, to lead IMTs. IMT levels range from IMT type 3 to IMT type 1, but within our study period, also include fire use management team types 1 and 2 (FUMT and FUM2, respectively). Type 1 IMTs are the most trained teams and are requested for the most complicated incidents (Canton-Thompson et al. 2008). Requesting an IMT or IC type 1 incurs significant costs and implies an extensive amount of resources utilized for the fire (Canton-Thompson et al. 2008).

Motivations for this Research

Natural resource management requires extensive planning yet extemporaneous decisions during disturbances. This dynamic environment, combined with working for the common good, is an inspiring path I wish to pursue. My interest in natural resource management motivated me to focus on decisions made by natural resource managers to better understand and learn from their choices and gain further insight into decision spaces within natural resource management. My prior background in water management, including completing 209 reports for a dam spillway rupture incident, informed my choice of this research topic.

In addition to personal interest in the field of decision-making in natural resource management, I was motivated by the critical need for the study of fire management in the face of climate change. As changes to our climate create increasingly complex, severe, and unpredictable conditions for natural resource managers, the need to address as much uncertainty as possible becomes increasingly critical. Future planning in natural resource management benefits from any increase in the knowledge of the level and direction of the influence of management, socioeconomic, environmental, or resource dynamic factors in decision-making.

CHAPTER 2: COMPLEXITIES IN DECISION-MAKING IN THE US NORTHERN ROCKIES, CHOICES OF SUPPRESSION TYPES DURING FIRE INCIDENTS

Wildland fire management is a complex decision arena that is increasingly impacted by climate change and rural development (Gude et al. 2008). Yet the relative influence of decision-making within the context of environmental, social, management, and fire characteristics have on fire management is not well understood (Canton-Thompson et al. 2008). This analysis explores suppression method decisions made during fire incidents, using data derived from Incident Command System (ICS) Situation Report (209) report data merged with other spatial data, to identify factors and their relationships with suppression method decisions.

The ICS has been recognized by the United Nations (UN) as the international model for managing emergency situations such as fire incidents, and it is used around the world (Fao.org). The United States (US) first utilized ICS on a national scale in 1983 (Buck et al. 2006), but it wasn't until 2004, when the National Incident Management System (NIMS) became mandatory in order to receive federal funding, that ICS was fully integrated into emergency management (FEMA 2017). All US agencies have adopted ICS as the emergency response system for their respective agencies, paving a way for internal and multi-agency cooperation within and across US regions. This institutionalized emergency response streamlines emergency management and when used properly, can be highly successful for managing emergencies (Jensen & Waugh 2014). ICS also provides a rich data source on fire incidents from 209 reports (Calkin et al. 2014).

As we move into a less predictable climate and the trend of longer fire years with larger, more frequent, higher complexity fires continues, the decision to select any suppression method has ecological and social consequences that are increasingly expeditious. A decision to delay, shift, or limit a fire's presence on the landscape requires consideration of many factors, including fuels present, current and/or anticipated weather, availability of resources, and political will of communities nearby. The shift in fire management to a more adaptive approach raises questions about the conditions under which fire managers are selecting full suppression or a less-than-full suppression approach.

Previously researched characteristics influencing suppression decisions

Much of the literature surrounding fire management highlights conditions that affect fire behavior and outcomes, suppression costs, and perceptions of fire. Fire policy and management studies have identified how policies, IMT types, and available resources shift response decisions and heavily influence strategies during incidents (Ingalsbee 2017; Stonesifer, Calkin, & Hand 2017; Thompson et al. 2017). Current policies perpetuate aggressive suppression strategies (Ingalsbee 2017), and fire policies often restrict suppression method decision space or allow for flexible management, thus impacting ultimate fire sizes (Thompson et al. 2017). Further, IMT types are highly influential in suppression method decision-making; in particular, type 1 IMTs are critical for direct and indirect attacks, and were indicated as not substitutable with alternatives (Stonesifer et al. 2017).

Social and psychological factors affect fire response and costs of suppression. Local communities may discourage anything other than full suppression and political leaders may pressure ICs to use more resources, tactics, or strategies (Canton-Thompson et al. 2008; Steelman & McCaffrey 2011). Much of the social science behind fire has focused on how fire perceptions influence fire risk adaptations (Paveglio et al. 2015; Paveglio, Abrams, & Ellison 2016). For example, increasing subjective knowledge of fire risks increases willingness to adopt fire risk adaptations (Martin, Martin, & Kent 2009). Previous work mentioned above focused on fire risk adaptation or fire management decisions during fire incidents impacting outcomes, specifically expenditures and landscape changes.

Researchers have explored socioeconomic factors associated with fire behavior, such as population density and distance to roads or railroads. In the Midwest, human activity - such as increased road and housing unit density - is positively associated with fire occurrence (Cardille, Ventura, & Turner 2001). Other researchers have highlighted the effects of WUI growth in the western US on fire management agencies; noting that with only 14% of the WUI developed, the average annual cost for agencies protecting private property from wildfire ranged from $630 million to $1.2 billion between 2000 to 2005 (Gude et al. 2008). The studies that analyzed human development effects on fire occurrence and suppression costs did not explore effects on the decisions to select certain suppression methods.

Weather and land cover significantly affect fire behavior and outcomes. Increased temperatures provide heat, decreased humidity dries out fuels, and wind provides oxygen to the fire, creating the “fire triangle” (Holsinger, Parks, & Miller 2016; Marlon et al.

2012; Williams 1982). Land cover classes, which can make up the fuels corner of the "fire triangle", change the severity of the burn, rate of spread, and complexity of the fire (i.e. crowning), but land cover classes also incorporate anthropogenic changes to the land such as developed areas (Brown, Hall, & Westerling 2004; Kramer et al. 2019; Lloret et al. 2002; Radeloff et al. 2018; Schwartz et al. 2015; Steelman 2016). Recent studies have investigated developed areas known as the wildland-urban interface (WUI) for the effects on fire behavior and risk, finding that the WUI exacerbates risks and effects of fire (Kramer et al. 2019; Radeloff et al. 2018). Research establishing these factors on fire behavior excludes the effect of landscape and weather factors on decisions ICs face when managing fires.

These previous studies have shed light on the many factors impacting fire behavior and outcomes, as well as economic effects of fire suppression strategies. Higher temperatures and lower humidity benefit fire, fuels such as grasses provide for fires that move swiftly across the landscape, and dense fuels increase risk to firefighter safety (Williams 1982). The use of regional or national incident management teams (IMTs) increase costs of fire suppression (Canton-Thompson et al. 2008). This study expands on this wealth of knowledge to identify how these factors impact decisions ICs make during fire incidents. In addition to these factors, however, this study also includes management (such as jurisdiction or IMT type) and socioeconomic factors (such as housing density or home values), the effects of which on suppression decisions are not well known.

Decisions about how to manage fires in the US are made at different levels (from local to national). Fire management changed substantially since ICS was adopted at the national level in 2004. In less than two decades, fire policies, land management plans, cooperative agreements, and Delegations of Authority have produced a complex implementation system with ambiguities that fire managers must address (Buck et al. 2006; Stephens & Ruth 2005). These ambiguities include uncertainties within rapidly changing environments, emergent groups within disaster response, and transformation of organizations and agencies during disaster response (Buck et al. 2006).

ICs report suppression methods chosen to manage the incident in 209s. The four suppression methods during 2008-2013 were full suppression, confine and contain, point-zone protection, and maintain and monitor. Full suppression indicates the IMT, led by the IC, "implies a strategy to "put the fire out," as efficiently and effectively as possible, while providing for firefighter and public safety" (NIFC 2011). This attempts to limit a fire's spread and potentially its complexity and severity, while increasing resources used during active management of the fire. Confine and contain is a strategy that uses natural and/or constructed barriers to restrict a fire to a defined area (NIFC 2011). When using point-zone protection, IMTs protect specific points from the fire without trying to line the fire's full edge (NIFC 2011). Maintain and monitor is the process of observing the fire and recording data collected (NIFC 2011).

Outcomes of fire suppression decisions have been explored to shed light on how similar factors impacting fire behavior or decisions made during fire incidents influence the ultimate costs of managing fires (Hand et al. 2017; Thompson 2013). These studies have utilized information from 209s, which provide daily streamlined information of fire incidents and have largely been used for economic analysis, as they are a rich information source for suppression costs. Results of these studies indicate that the complexity of agency policies, socio-political pressures, and resource availability lead to increased suppression costs (Canton-Thompson et al. 2008). The 209s include an extensive amount of information beyond what has been examined in relation to fire management costs, thus leaving a gap in current research.

The complex factors that influence the daily decisions made by incident commanders during fire remain understudied. Providing management and socioeconomic factors associated with the decision to select one of four suppression methods fills the gap in the research thus bringing scientists and managers closer to understanding the context surrounding decisions made during fire incidents. The ICS system offers opportunity to address this knowledge gap through the widespread adoption of consistent documentation of fire-management decisions.

Previous research, such as establishing fuels' effects on fire behavior, relied on GIS and/or field data for analyses (Kasischke, Williams, & Barry 2002; Lampin-Maillet et al. 2010; Syphard & Keeley 2015). Fire management cost analyses utilized 209s and statistical software (Hand et al. 2017). Studies that analyzed social and psychological effects on fire costs and adaptation measures relied largely on qualitative methods (Canton-Thompson et al. 2008; Thompson 2014). By using mixed methods in this study, we capture the context surrounding decisions during fire incidents, provide an integrative analysis, and increase validity given the limitations of individual methods.

This study looks at how management factors, such as the level of the incident management team assigned to the fire, and socioeconomic factors, such as WUI class and home values, influence suppression decisions (in addition to environmental and fire characteristics). Specifically, we ask: what management, socioeconomic, environmental, and fire characteristics were associated with full suppression, point-zone, confine and contain, and maintain and monitor suppression types reported on fires occurring between 2008 and 2013? The goals of the research are to examine management, socioeconomic, environmental, and fire characteristics that have impacted suppression decisions in managing fires in the northern Rocky Mountains, and to identify changes that might assist agencies in fire policy development and ICs in selecting less-than-full suppression approaches when appropriate.

METHODOLOGY

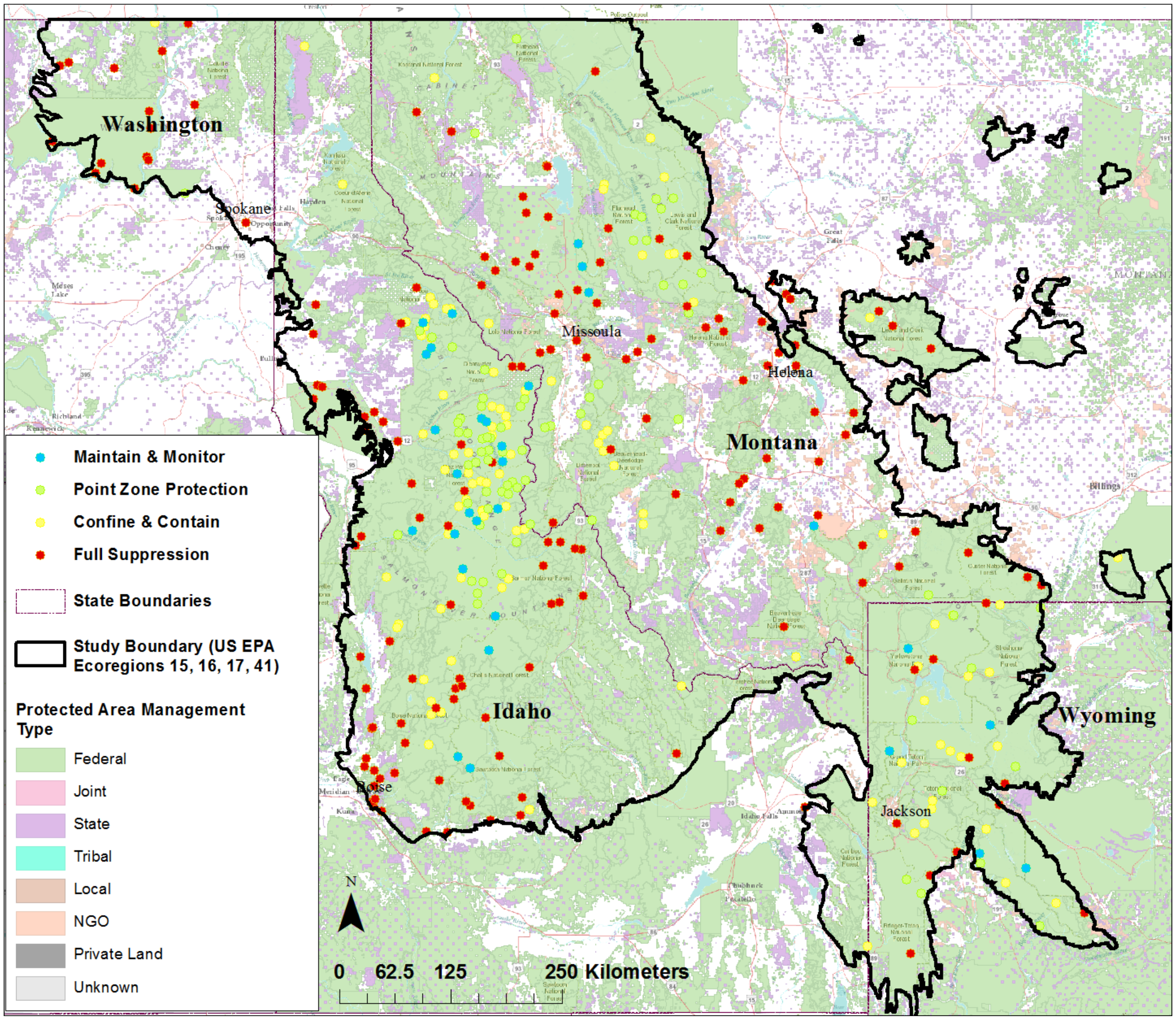

Figure 1. Map of the study area including fire incidents with maximum fire size of 100 acres or more

Study Area

Using US Environmental Protection Agency Ecoregions 15, 16, 17, and 41, the northern US Rocky Mountains includes the northeast corner of Washington, northern majority of Idaho, western portion of Montana, and northwestern corner of Wyoming (Figure 1) (Harvey, Donato, & Turner 2016). Land cover is primarily forest or woodland (74% of the landscape). Subalbpine forests, which account for 45% of total forested area, are at highest elevations with infrequent, high-severity fires, and are dominated by subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), lodgepole pine (*Pinus contorta var. latifolia*), and whitebark pine (*Pinus albicaulis*) (Harvey et al. 2016; Schoennagel, Veblen, & Romme 2004). At elevations of 750-2500m, mid-montane forests, having mixed severity and frequency of fires, account for 53% of total forested area and are dominated by Douglas-fir (*Pseudotsuga menziesii var. glauca*), western larch (*Larix occidentalis*), ponderosa pine (*Pinus ponderosa*), limber pine (*Pinus flexilis*), and quaking aspen (*Populus tremuloides*) (Harvey et al. 2016; Schoennagel et al. 2004). At 500-1500m, low-montane forests account for 3% of total forested land, have a high-frequency and low-severity fire regime, and are dominated by ponderosa pine, limber pine, and western juniper (*Juniperus occidentalis*) (Harvey et al. 2016; Schoennagel et al. 2004).

Public lands account for the majority of the study area, and of the public lands, United States Forest Service (USFS) manages 77%, Bureau of Land Management manages 6%, and Bureau of Indian Affairs and National Park Service each manage 4%. US Army Corps of Engineers, US Fish and Wildlife Service, state agencies, and non-governmental organizations manage the remaining 9% of public land.

Data Sources and Processing

This study incorporates interviews and quantitative analyses to capture the context surrounding decisions during fire incidents, provide an integrative analysis, and increase validity given the limitations of individual methods.

I utilize information from 4,808 209s from 2008-2013 collected by USFS and provided by Karen Short at USFS, spatial data from a variety of sources (see Table A1), and interviews with key informants and ICs. The 209s are completed to various extents and at various frequencies during fire incidents, depending on fire size and complexity. Agency personnel including ICs and line officers complete 209s and submit them to regional coordinators for assessments of fire incident statuses and fire management resource needs. 209s are also sent to national agency personnel and distributed among congressional committee members; thus, 209s also serve to inform others beyond agency personnel.

I selected 209s from fire incidents within the study boundary with maximum fire size of at least 100 acres. This minimum fire size removed nearly all prescribed fires, except for the fires in which the incident classification shifted from a prescribed burn to a wildland fire incident (i.e. a prescribed burn that escaped the planned area). Incidents without suppression method information were also removed.

Dependent variable

The dependent variable is the suppression method reported in 209s per day of each fire incident. Suppression method was the dependent variable in the ordinal and binomial analyses. The binomial analysis compared full suppression (1) with non-full suppression (0). The ordinal analysis treated suppression method as an ordered categorical variable, with the following levels: maintain and monitor (1), point zone protection (2), confine and contain (3), and full suppression (4). I ordered the suppression method categories for the ordinal analysis based on their definitions and interviews with key informants and ICs.

Independent variables

Independent variables include management, socioeconomic, environmental, and fire behavior characteristics (Table 1). The 209 data provided many independent variables: IMT type (which was used to create IMT rank, grouping IMT types based on unit/position training and complexity), terrain, and unit type (federal vs. non-federal jurisdiction) in which the incident occurred (Table 1). Hypotheses (Table 1) and sources (Table A1) are also provided.

Table 1. Variable Descriptions and Hypotheses

Independent Variable	Description (units)	Mean	Range	Hypothesis
Management Variables				
Report Date	Date of report; given per day of incident out of 365 (Julian day)	241.9	73 - 363	Fires that occur earlier in the year will be associated with full suppression
National Preparedness Level	National Preparedness Level (1-5) per day of incident (unitless)	2.91	1 - 5	Increased National Preparedness Level will be associated with full suppression
IMT Rank	Ranking of incident commander or management team based on IMT type, based on position training requirements/ incident complexity (unitless)	4.1	1 - 7	The lowest and highest levels of IMTs/ICs will be associated with full suppression, the IMTs/ICs in between will not have strong associations
Ownership State	State in which the fire occurred (unitless)	1.94	1 - 4	The four states in our study boundary will have weak associations with suppression methods; MT will be associated with full suppression
Unit Type	Type of unit managing the fire or serving as lead agency; non-federal (0) (state, interagency, or county/local) or federal (1) (unitless)	0.89	0 - 1	Incidents on non-federal land will be associated with full suppression
Perceived Growth Potential	Predicted future fire growth estimated by officer completing	2.45	1 - 5	Higher growth potential will be associated with full suppression

	the 209, ranging from low to extreme (unitless)			
Socioeconomic Variables				
Median Home Values (based on $US) (2010)	Median home value within five kilometers surrounding fire's point of origin (unitless)	5.39	1 - 11	Increased median home values will be associated with full suppression
WUI Flag	Indicator that identifies the area within five kilometers surrounding fire's point of origin as intermix (1), interface (2), or neither (0) (unitless)	0.05	0 - 1.27	WUI flags (1 or 2) will be associated with full suppression
Seasonal Housing Unit Density	Seasonal housing unit density per square kilometer within fire kilometers surrounding fire's point of origin (housing units/km^2)	1.74	0 - 111.84	Seasonal housing unit density will be more associated with FS, CC, and PZ and less associated with MM
Housing Unit Density	Housing unit density per square kilometer for the five kilometers surrounding fire's point of origin (housing units/km^2)	5.89	0 - 766.44	Housing unit density will be more associated with FS, CC, and PZ and less associated with MM
Distance to Road/Rail	Distance to nearest road or railroad from the fire's point of origin (km)	194.3	1 - 375	Distance to road/rail will be negatively associated with full suppression
Environmental Variables and Fire Behavior Characteristics				
Area (Log of)	Log of the area reported in 209 (acres)	72.52	1 - 160	An increase in fire size will be associated with full suppression
Duration	Duration of the incident, determined by the final report DOY and the start DOY in the 209 (days)	22.79	0 - 164	Higher fire duration will be associated with less-than-full suppression
Cause	The cause of the fire (either lightning (1), human (2), unknown (3), under investigation (4)) (unitless)	1.32	1 - 4	Human-caused ignitions will be more associated with full suppression
Primary Fuel Model	Primary fuel model for landscape (Grass=1-3, Shrub=4-7, Timber Litter=8-10, Logging Slash=11-13; levels within each) (unitless)	3.78	1 - 13	An increase in primary fuel model will be associated with less-than-full suppression
Primary Land Cover Class	Area (km2) within the 5km radius of the fire point of origin that is classified as water, developed, cropland, evergreen forest or barren, deciduous or mixed forest, and shrub/grass, as an ordered factor	4.32	1 - 6	Shrub/grass will be associated with increased suppression, and the most dense cover class, forest, will be associated with less-than-full suppression
Aspect	Aspect of the land at the fire point of origin (N, NW, NE, NNW, NNE, ENE, WNW, etc.) (^{o})	176	1 - 374	More fires will occur on north-facing slopes due to fuel availability. Aspect will be associated with less than full suppression
Terrain	Description of terrain, from low to extreme; includes steepness, difficulty to navigate (unitless)	3.38	1 - 5	More extreme terrain will be associated with less-than-full suppression

Elevation	Elevation of weather station (m)	205	1 - 374	As elevation increases, occurrence and intensity of fire increases. Low elevation fires will be associated with full suppression
Temperature	Temperature (^{o}C)	168.1	1 - 346	Higher temperatures decrease IMT control of the fire, so increased temperatures will be associated with less-than-full suppression
Relative Humidity	Percent humidity (%)	127.2	1 - 241	Lower RH decreases IMT control of the fire and increases fire severity; increased relative humidity will be associated with full suppression

Certain independent variables were either too inconsistently present in 209s, or were not present at all, thus requiring either additional sources or the creation of new variables. Weather was too inconsistent in the 209s and external weather data from PRISM, joined to each fire incident based on the closest weather tower (Table A1), was not accurate enough. In some cases, the closest tower to a fire incident was up to 15km away, and could be at an entirely different elevation. Comparing weather tower data with weather data in the 209s, a t-test showed they are not interchangeable. Weather variables were excluded from analyses.

Median home value, national preparedness level (NPL), WUI and housing density information, and land cover class, were externally sourced (see Table A1) because they were not provided in the 209s. National Multi-Agency Coordination Group (NMAC) establishes NPL throughout the year depending on fuel and weather conditions, resource availability, and fire activity (NIFC.gov). Duration, log of area, and IMT rank were created based on similar variables in the 209s (see Table A1). I grouped unit type into a binary expression (federal vs. not federal), grouped IMT types into ranks based on training requirements and capabilities (ranks 1-7), grouped and ranked cause of ignition

(Lightning=1, human/under investigation=0), applied the natural log to fire area, and took the mean aspect within 5km of the fire origin point.

Independent variables pulled from spatial sources include elevation, aspect, weather, distance to road/railroad, land cover class, and WUI flags. These were spatially joined to incidents in ArcMap 10.5.1 (ESRI 2011) based on fire points of origin and subsequently imported into R (R Core Team 2018). Independent variables from non-spatial sources were pulled from sources and joined to 209 data in R. All created variables were created in R.

Statistical Analysis

Correlation matrices revealed high correlations between state and longitude (0.78), report date and duration (0.68), and perceived growth potential and terrain (0.53), so I removed state, duration, and perceived growth potential from both models. The cutoff for correlation among variables was 0.40 (Table A2). A PCA of 15 land cover revealed several strong associations among land cover classes. Land-cover classes were grouped based on the PCA and the primary land cover class was identified within a 5km boundary surrounding each fire point of origin. I consulted correlation matrices and conducted a variable inflation factor (VIF) analysis for multivariate reduction. VIF analyses showed WUI Flag caused significant multicollinearity, so it was removed.

Addressing my research question of factors that impact suppression method decisions, I applied a generalized additive mixed model (GAMM) (Table 2). GAMM is a linear regression that allows for an ordinal response and mixed effects to address temporal and spatial autocorrelation (Table 2). To address spatial autocorrelation, longitude and latitude were added to regression models via splining to add spatial dependence to the model, avoiding violation of the assumption of independent residuals. To address temporal autocorrelation, a random identification number was assigned to the daily observations (n = 4,808) and that variable was added to regression models as a random effect, assigning an identity penalty, also known as a ridge penalty (Wood 2008).

An exhaustive variable selection search based on AIC to achieve the best model removed median home value and elevation from the binary response model. The exhaustive search for the ordinal response model did not remove additional variables. The final set of 13 predictors for the binary response model include: report date, NPL, IMT rank, unit type, seasonal housing unit density, housing unit density, cause of ignition, fire area, terrain, aspect, primary fuel model, primary land cover class, and distance to road/railroad. The final set of 15 predictors for the ordinal response model include: report date, NPL, IMT rank, unit type, seasonal housing unit density, housing unit density, median home value, cause of ignition, fire area, elevation, aspect, terrain, primary fuel model, primary land cover class, and distance to road/railroad.

Interviews

I interviewed three key informants identified by collaborators in the region. These interviews served to verify my interview questions and clarify questions about the 209 data. Second, ICs (n= 8) were identified from fire incidents reported in the 209 data. I selected ICs for interviews by selecting fires in the dataset during which the suppression method reported changed. Identifying ICs listed in these incidents and beginning with ICs reported on the two days before, the day of, and the two days after suppression method change (n=82), I reached out to those whose contact information could be found online (n=23) and received thirteen responses, two of which the IC deferred us to coworkers (who were not ICs in our study) and one explained I had the wrong person. Two ICs initially postponed interviews, but have not been able to be reached since. No other ICs from incidents during which suppression method changed could be reached due to lack of available contact information or lack of response.

Of the eight interviewees who were identified as ICs in the 209 data during the study period, seven still work in the study area at federal and state agencies or as consultants in fire management. Qualitative information from interviews was primarily utilized deductively by identifying quotes that provide context for quantitative variables. I also inductively identified the themes of reflections on 209 reporting and perspectives on climate and future forests, given the interest of interviewees on these topics.

The Institutional Review Board (IRB) approved interview questions (Appendix A), initial contact, oral consent form, and storage of interview data (Project ID 2016-1582). Consent for recording interviews and use of quotes was verified at the start of each interview. Interviews were conducted between June 27 and September 12, 2019 via phone and recorded and transcribed.

RESULTS

From 2008 to 2013, ICs completed incident reports in the Northern Rocky Mountains for 374 incidents on 4,808 days. Of the 335 incidents (90%) that did not have a change in suppression, 47% reported full suppression, 27% reported confine and contain, 19% reported point-zone protection, and 7% reported maintain and monitor. Of the daily reports, 41% reported full suppression, 24% reported confine and contain, 28% reported point-zone protection, and 6% reported maintain and monitor. Of the 39 incidents (10%) that had a change in suppression, the most common changes were between confine and contain and point-zone protection and between full suppression and point-zone protection.

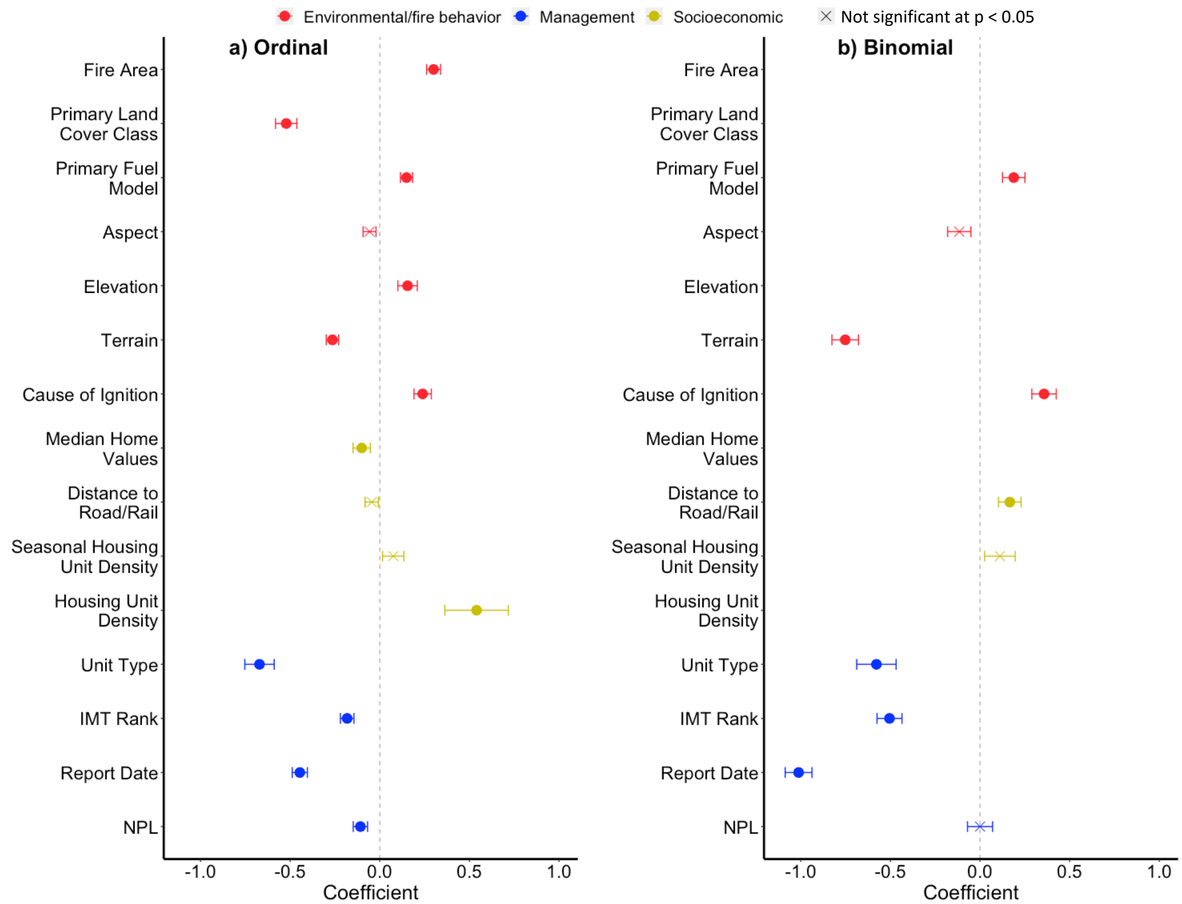

Figure 2. Standardized results for the ordinal (null deviance explained = 0.356, n = 4,808) and binomial model (adjusted R^2 = 0.709, n = 4,808) (error bars are standard error)

Primary land cover class, housing unit density, unit type, and report date were most strongly associated with suppression methods in both models (Figure 2). Tables 2-4 provide results for both the binomial and ordinal models, split into three tables for viewing grouped by variable type. Interviewees indicated most factors included in our analysis influence suppression method decision-making (Tables 2-4).

Table 2. Management model coefficients and associated interview responses; the ordinal model and binomial models include all variables in Tables 2-4.

Independent Variable	**Standardized Estimate, Ordinal** (FS=4, CC=3, PZ=2, MM=1)	**Standardized Estimate, Binomial** (FS=1, NFS=0)	**Interview Responses to Questions of Factors Included in Suppression Method Decision-Making (factors that impact decision to choose or change suppression method)**
National Preparedness Level, Report Date	-0.108** -0.446***	-0.0001 -1.012***	"If you're at a PL 5, that means multiple regions are going at once, so as far as getting resources to implement your plan and get in and deal with a larger fire, it gets real difficult. That is definitely a driver. We end up putting out some fires that in other years, we would manage on the landscape but there just wasn't the resources, wasn't the people to get it and we were able to catch them while they were small and do it safely." "I think the state of fuels is a big one, and I also think the time of year and the timing of the fire." "regardless of the type complexity, whether it's a 1, 2, or 3, or 4 or 5, on a forest or jurisdiction, that high PL levels are in the latter part of the summer months, generally – generally – will reduce your chance of getting the types of resources that you need"
IMT Rank	-0.182***	-0.505***	"… type 1 and type 2 teams - a lot of those teams are suppression-minded" "the best team is almost always – if not always - the local team, it's the team that you know. It's your team. A lot of places have type 3 teams made up of local staff that live and work there all the time, they know the environment, they know the ground … when you start bringing in people from the outside, it starts getting more difficult."
Unit Type (Jurisdiction) (federal (1) vs. non-federal (0) land)	-0.671***	-0.578***	"When you look at state jurisdictional lands, and certainly private… In those cases, it's going to be full suppression, direct attack, with indirect strategies" "if there's state jurisdiction involved, it's going to be minimize acres burned, aggressive, direct attack to put the fire out." "there are a lot more varied opportunities in the federal jurisdiction than there is certainly on the private and the state"

Significance codes: ***p<0.001, **p<0.01, *p<0.05

Management Variables

All five management variables were significant in at least one model (Table 2). Full suppression was most likely when reporting date was earlier in the fire season, IMTs were regional or national, and fires were on non-federal lands. Results for the escalation of fire suppression choices (from 1 to 4) were similar, but fire management was less aggressive when NPL was high (Table 2). NPL was mentioned as an important factor by most interviewees. One interviewee stated, "if you're in the upper PLs, you may not get your resources that you need to manage the fire the way you want to manage that fire, so you have to adjust based on your NPL" (Interview #10). In line with NPL, suppression method depends on resource availability: "We look at tactics that we can actually do and be successful with, and that really points us toward more indirect strategies, and aerial ignition, and we can back fire down to a road or something that is in place, you know a natural barrier, because we just don't have the crews to go direct" (Interview #9).

National and regional IMT were always more likely to suppress fires, and human-caused fires were treated more aggressively than fires ignited by lightning (Figure 5). Interviewees listed IMT type as another important factor associated with suppression method. National or regional teams rely more on tactics associated with their "home" topography, whereas local teams will be better equipped for flexible suppression strategies: "the best team is almost always – if not always - the local team, it's the team that you know… they know the environment, they know the ground" (Interview #9).

Socioeconomic Variables

Full suppression occurred most often where housing density was higher and when fires occurred closer to roads or railroads (Table 3). Median home value was significant in the ordinal model and was negatively associated with increased suppression, contrary to our hypothesis. Among the four fire management categories, fire management was more aggressive where housing density was high (Table 3).

Table 3. Socioeconomic model coefficients and associated interview responses; the ordinal model and binomial models include all variables in Tables 2-4.

Independent Variable	**Standardized Estimate, Ordinal** (FS=4, CC=3, PZ=2, MM=1)	**Standardized Estimate, Binomial** (FS=1, NFS=0)	**Interview Responses to Questions of Factors Included in Suppression Method Decision-Making (factors that impact decision to choose or change suppression method)**
Housing Unit Density Seasonal Housing Unit Density,	0.540** 0.075	1.40*** 0.111	"You drive down a road you just thought was a logging road, and there's 20 houses at the end of it. That becomes a challenge for us because that fundamentally changes how we approach the fire." "I do see fragmentation of the forest. It makes it harder for you to make decisions on managing fires within those areas." "Usually, you're into where we're burning houses down and you're in that kind of social/political realm when it bumps up to that type 1 team."
Distance to Road/Rail	-0.045	0.166**	"we look at tactics that we can actually do and be successful with, and that really points us toward more indirect strategies, and aerial ignition, and we can back fire down to a road or something that is in place, you know a natural barrier, because we just don't have the crews to go direct."
Median Home Values	-0.101*	Removed based on exhaustive search	-

Significance codes: ***p<0.001, **p<0.01, *p<0.05

Environmental and Fire Behavior Variables

Full suppression was more likely at lower elevations, in more complex terrain, and when relative humidity was low (Table 4). Human-caused ignitions were more associated with full suppression, confirming our hypothesis. Primary land cover class had a negative relationship with increased suppression and strongly influenced suppression method choices (Table 4).

Table 4. Environmental and fire behavior model coefficients and associated interview responses; the ordinal model and binomial models include all variables in Tables 2-4.

Independent Variable	**Standardized Estimate, Ordinal** (FS=4, CC=3, PZ=2, MM=1)	**Standardized Estimate, Binomial** (FS=1, NFS=0)	**Interview Responses to Questions of Factors Included in Suppression Method Decision-Making (factors that impact decision to choose or change suppression method)**
Temperature, Relative Humidity	N/A	N/A	"generally to me it's when you either have favorable conditions that have occurred or are existing that allow you to shift your suppression strategy differently, or you have an unexpected event that takes place that is driven by fuel conditions or fire weather conditions that change then allow you or force you to have to shift your strategy"
Cause of Ignition	0.239***	0.357***	"Cause of ignition is a big one because federal fire policy allows a lot more decision space in a natural fire start."
Terrain	-0.264***	-0.752***	"fuels and terrain, they certainly go without saying that's obviously going to influence your capabilities of suppression methods" "As far as terrain, terrain is a huge influence on suppression methods, especially nowadays with the beetle kill and the different state of our forests. Being able to find those places that are going to be good for holding the fire."
Elevation	0.155**	Removed based on exhaustive search	"Weather, terrain, and fuels that's driving a lot of our decisions. And even in the places that's the wiggle room the state of MT has – if we can't fight the fire up there, we're not going to chase the fire up there. We're going to back off and fight the fire where we can."
Aspect	-0.057	-0.116	-

Primary Fuel Model	0.149***	0.188**	"fuels and terrain, they certainly go without saying that's obviously going to influence your capabilities of suppression methods"
Primary Land Cover Class	-0.522***	-1.501***	"Our forests are kind of overdue for fires, which makes them super dangerous for the folks on the ground. So we really got to look at the fuel loading, the snag factor, and look at those suppression difficulty indexes to see if we can suppress the fire where it's actually at."
Area (Log of)	0.30***	1.167***	"if the fire gets to a certain size, you know you're not going to be able to do 100% suppression on it." "the only difference between a Type 3 and a Type 1 [team] is your higher complexity of the conditions, and jurisdictions, and the values at risk, and resources and size of the fire"
Duration	N/A	N/A	"some of the more regional/state/local teams, they're not going to commit those resources to longer duration fire" "if you have a specific mission to protect that specific value at risk and you need a specific resource to do it with, you identify that on the 209 that you need it for a set duration, it's more likely that you might receive that resource on a short duration and turnaround because they are on high demand"

Significance codes: ***p<0.001, **p<0.01, *p<0.05

The relationships among the variables are of note: several relationships changed other variables' impacts on suppression method decisions. National IMTs were more aggressive than local IMTs, but across all IMT types, more aggressive suppression was implemented on human-caused fires than lightning-caused fires (Figure 5). At higher housing densities and earlier in the year, full suppression was more likely; but later in the year, that likelihood approached other suppression methods (Figure 6). Maintain and monitor and point-zone protection were strongly associated with minimal housing densities (Figure 6).

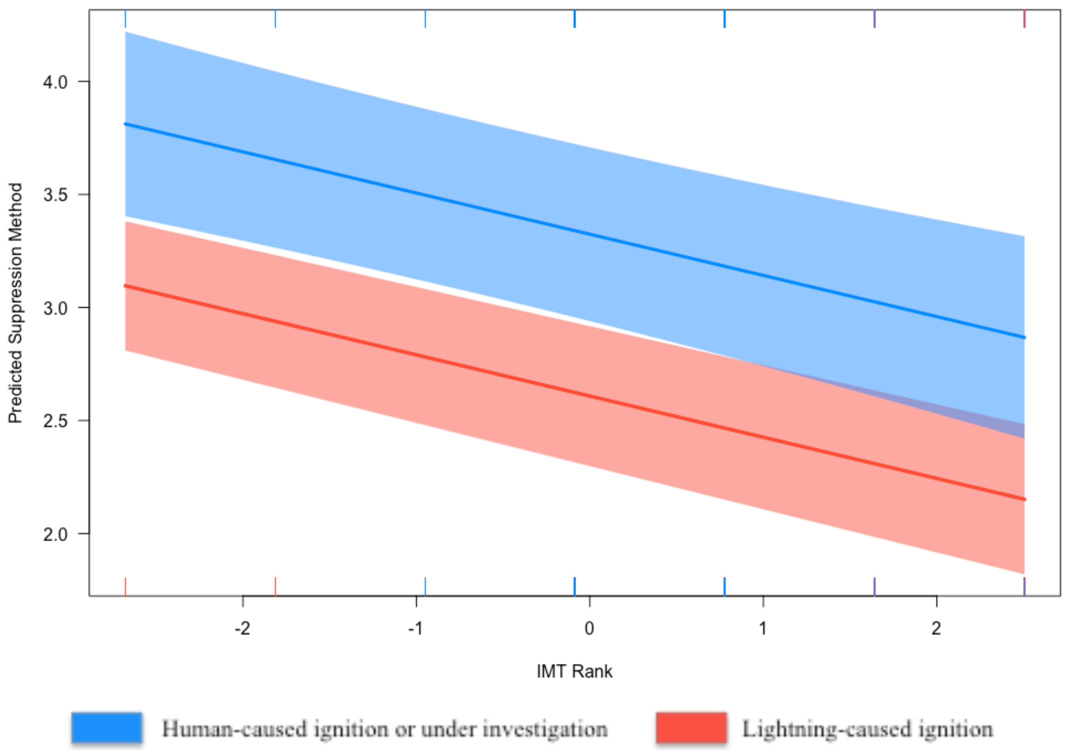

Figure 5. Effects of IMT rank on suppression method, cross-sectioned by cause of ignition (shading is 95% CI)

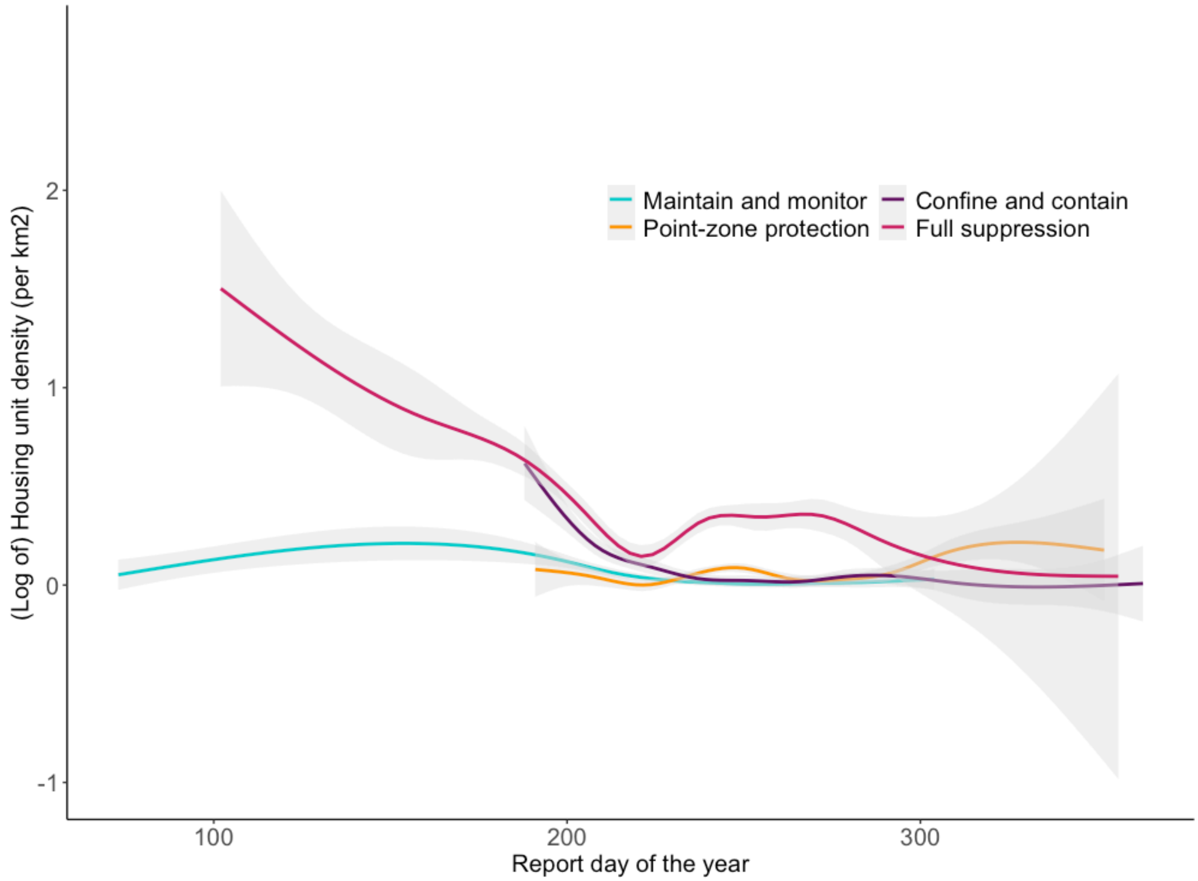

Figure 6. Suppression methods by report day of the year and housing unit densities (shading is standard error)

Reflections on 209s

Responding to questions on the use of 209s, nearly all interviewees indicated that 209s were effective for reporting certain data only when the form was completed properly. Several indicated that the benefit of 209s to ICs is resource acquisition, and agencies benefit from 209s by getting the full picture of the incident – if that picture is a simple one: "it's amazing how many people inside the beltline actually read the 209s and will even look at the [incident action plans] to kind of drill down into the objectives, and what you have, and what you're getting accomplished" (Interview #9); "if it's a straight, full-perimeter objective, the 209 does pretty well. If it's something less than a full-perimeter objective, the 209 fails to capture that objective" (Interview #6). Interviewees indicated that any ineffectiveness of 209s may stem from the shift in fire regimes and fire management: "209s have been around a long time – they were built when the original format was derived when 90% of the time, we were doing a full-perimeter objective" (Interview #6).

Most interviewees indicated that the most helpful management tool for responding to or achieving goals for incidents is the Delegation of Authority, which grants the IC authority to carry out actions during the incident and can be written or verbally communicated. In addition to that authorization, most interviewees listed land management plans as critical documents, and within those, management action points.

Interviewees mentioned there is an element of politics within 209 reporting:

> *In the 209, we've learned there are some politics in reporting what we report – we might report confine and contain even though we aren't going to take any action whatsoever until the event the fire crosses the divide. That has a lot to do with being good players with our cooperators, in saying we never intended this fire can do whatever it wants, so now we might call it confine and contain because our intention is to limit it to the wilderness or federally managed land.* (Interview #4).

Other interviewees described the element of politics within 209 reporting as more of a tool: "if you're in dire needs of a certain kind of resource, you'll include language in there that speaks to that need for that resource" (Interview #10). Interviewees indicated social or political factors are present: "if there is a political will to do something … your hand is forced there" (Interview #7).

Changing Fire Regime Conditions

Reflecting on changing fire regimes, interviewees indicated the changes that concern them the most for the region (in no particular order): climate change, smoke (air quality), community support and understanding, development of the WUI, forest conditions (fuel loads, age class diversity, disease, and insects), and increased fire sizes. As for those changes that will impact suppression decisions, interviewees listed (in no particular order): public support, understanding, and knowledge; how much fire can be on the landscape now, reducing the fire on the landscape in the future; national fire policy; and perception of fire management and suppression. See Appendix C for more on the future of suppression decision-making.

Interviewees stated the importance of individual relationships with agency administrators and line officers, and the importance of good public relations on the decision-making process as well as future factors on IC autonomy to select less-than-full suppression methods.

Interviewees were asked to consider the necessary precursors for more autonomy in the future to select less-than-full suppression, given the right conditions. The interviewees identified: improved fuels management, increased risk tolerance, improved land management, decreased liability and/or increased agency support of line officer decisions, public support, agency leadership acknowledgement of the value of fire on the landscape, positive reinforcement of reporting less-than-full suppression, increased risk management training, perception of fire as natural, individual comfort with decision-making, redefining the nomenclature of ‘suppression’ and ‘managing a fire’. Of those listed, risk tolerance was referenced most by interviewees (n = 4).

One dichotomy mentioned in interviews is the agency personnel and IC mindset of the landscape remaining what it has been or currently is, versus transitioning into something else due to effects of climate change. This dichotomy is apparent even among those interviewed; one interviewee remarked, “My biggest fear is that my kids aren’t going to have a national forest landscape to enjoy, because the rate at which they’re burning - while it is less than what we historically burned - the conditions for which their burning under are a lot more on the extreme end” (Interview #10), while another rhetorically asked, “ok, there aren’t any trees. Well, is that a bad thing?” (Interview #4).

DISCUSSION

This research establishes the importance of management and socioeconomic variables in IC decision-making, in addition to the well-explored effects of environmental and fire characteristics (Birch et al. 2015; Holsinger et al. 2016). The intention of this study was to identify some of those additional variables and quantify their impact on suppression decisions. I quantified relationships of management, socioeconomic, environmental, and fire behavior factors in suppression decisions during fire incidents. The interviews provided context for the quantification of the relationships of the variables and explained additional circumstantial influences on the suppression decisions.

The impact on suppression type by unit type, IMT rank, and report date was stronger than anticipated, and the negative direction of the relationships aligned with hypotheses and interview results. Such strong relationships emphasize the need for fire management studies to include management variables in analyses. As hypothesized, fires that occurred earlier in the fire season were more likely to be fully suppressed. Weather conditions are often less extreme, which allows for full suppression and coopting resources that may be needed later. Likelihood of full suppression on non-federal lands and nearer to roads is also associated with these areas having higher human populations and human infrastructure, and possibly more proscriptive state-level fire management.

Our hypothesis was that higher NPLs would be associated with full suppression based on NPLs indicating conditions favoring extreme fire behavior, thus a desire for minimal fire on the landscape (Dunn, Calkin, & Thompson 2017). NPL had a negative association with full suppression, and interviewees emphasized NPL's influence on their decision space regardless of other factors. As NPL increased, decision space to use adaptive suppression methods decreased. As interviewees pointed out, this is due to limited resource availability. At higher NPLs, there were insufficient resources to apply full suppression on fire incidents. Interviewees indicated that some factors influence effects of other independent variables, such as NPL, which has direct implications for unit type and resource availability.

Also as hypothesized, full suppression was more likely to occur when the regional or national, rather than local, IMTs were involved. These teams are usually called upon when perceived risk to people or resources is high, and when fire size and behavior exceeds the resources available locally, an association described by interviewees. However, the relationship between IMTs and suppression method has a tangled causality: conditions impacting IMTs also impact suppression method decisions. Whether regional or national teams (i.e. type 1 or type 2 IMTs) are more inclined to choose full suppression and/or if the factors that necessitate those teams are driving that suppression method is a question for further analysis.

Interviewees listed values at risk, private property, and WUI as factors in increasing suppression, and regression analyses showed housing density was strongly associated with increased suppression, in line with previous studies (Bar-Massada, Radeloff, & Stewart 2014; Radeloff et al. 2018). With median home value significant in the ordinal response model (negative relationship with increased suppression, suggesting as home values increase, ICs are more likely to select less-than-full suppression), additional socioeconomic variables should be considered in future analyses.

A limitation to this investigation is the use of temporally auto-correlated data. Each fire incident utilized in this research ranged from 2 to 120 days, and each day impacts the day before and the day after. I added the randomly-assigned identification number of each observation to both models as a random effect, which accounted for some effects of temporal autocorrelation. Future analyses of 209 data should incorporate more direct approaches to account for temporal autocorrelation.

Many lessons learned in fire management can be applied to different regions and countries; this investigation is of a relatively sparsely populated, high-elevation region that is comprised largely of public land owned by the US federal government but also contains significant rural residential development and urban centers.

Conclusion

These results indicate management and socioeconomic factors, such as unit type (jurisdiction), home values, and IMT rank are important to add to more commonly examined topographic and fire characteristics. The qualitative results from our study demonstrate their necessity for the broader context of IC decisions and the politics of 209 reporting. Support for less-than-full suppression when appropriate will require changes in management to support IC decisions that include the complex social-ecological context for fire.

If current WUI development and climate change effects trends continue, then decision space to select less-than full suppression methods will diminish. If federal and state policies expand the autonomy to select less-than full suppression methods, then we may see an increase in the selection of those methods.

CHAPTER 3: CONCLUSION

Additional Considerations

One finding of interest is the association between the cause of ignition and the WUI classification. In our correlation matrix, WUI flags are associated with human-caused ignitions: more human-ignited fires are associated with the WUI, even in a more rural setting such as our study area, which is aligned with previous studies delineating the fire management implications of WUI growth in the US (Kramer et al. 2019; Radeloff et al. 2018). Also of note is the correlation between elevation and median home value: as elevation increased, median home value increased. This is of some importance to note because as terrain becomes more extreme, it is less associated with increased suppression, yet as elevation increases, it is more associated with increased suppression and higher home values.

From the interviews there stems a paradox of using 209s to help in resource competition, yet the acknowledgement that so many high-level agency staff in Washington DC utilize the information for policy implications. The dichotomous roles of 209s connects this research to existing studies that emphasize the need for changes in fire policy in the US (Steelman & Burke 2007).

Recommendations

Policy implications from my research include the role of national policy and rhetoric on individual decisions made during fire incidents. Interviewees expressed the agency support for on-the-ground decisions as a precursor to increased autonomy in choosing less-than-full suppression methods in the future. Some programs and tools to support ICs are already in place, as mentioned during interviews. These include the GNA, FireWise communities, Wildland Fire Decision Support System (WFDSS), and forest action councils. Future research to identify fire policy's influence on suppression methods could further investigate these tools and approaches.

Areas for Continued Research

Given the interviewees' attention to the Delegation of Authority and land management plans (and MAPs within them), I recommend investigation of the effect of land management plan language on fire suppression decision-making. Interviewees listed public understanding, perception, and tolerance of fire as key drivers of their decisions; future analyses of fire regimes and management could investigate how and to what extent these drivers impact suppression method decisions.

LITERATURE CITED

Anderson, Hal. 1982. *Aids to Determining Fuel Models For Estimating Fire Behavior*.

Bar-Massada, Avi, Volker C. Radeloff, & Susan I. Stewart. 2014. Biotic and Abiotic Effects of Human Settlements in the Wildland-Urban Interface. *BioScience* 64(5):429–37.

Birch, Donovan S., Penelope Morgan, Crystal A. Kolden, John T. Abatzoglou, Gregory K. Dillon, Andrew T. Hudak, & Alistair M. S. Smith. 2015. Vegetation, Topography and Daily Weather Influenced Burn Severity in Central Idaho and Western Montana Forests. *Ecosphere* 6(1):art17.

Brown, T. J., B. L. Hall, & A. L. Westerling. 2004. The Impacts of 21st Century Climate Change on Wildland Fire Danger in Western United States: An Application Perspective. *Climatic Change* 62(365–388):365–88.

Buck, Dick A., Joseph E. Trainor, & Benigno E. Aguirre. 2006. A Critical Evaluation of the Incident Command System and NIMS. *Journal of Homeland Security and Emergency Management* 3(3).

Calkin, D. E., J. D. Cohen, M. A. Finney, & M. P. Thompson. 2014. How Risk Management Can Prevent Future Wildfire Disasters in the Wildland-Urban Interface. *Proceedings of the National Academy of Sciences* 111(2).

Canton-Thompson, J., K. M. Gebert, B. Thompson, G. Jones, D. Calkin, & G. Donovan. 2008. External Human Factors in Incident Management Team Decisionmaking and Their Effect on Large Fire Suppression Expenditures. *Journal of Forestry* 106(8):416–24.

Cardille, Jeffrey A., Stephen J. Ventura, & Monica G. Turner. 2001. Environmental and Social Factors Influencing Wildfires in the Upper Midwest, United States. *Ecological Society of America* 11(1):111–27.

Donovan, Geoffrey H. and Thomas C. Brown. 2007. Be Careful What You Wish for: The Legacy of Smokey Bear. *Frontiers in Ecology and the Environment* 5(2):73–79.

Dunn, Christopher J., David E. Calkin, & Matthew P. Thompson. 2017. "Towards Enhanced Risk Management: Planning, Decision Making and Monitoring of US Wildfire Response." *International Journal of Wildland Fire* 26(7):551–56.

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

FAO.org. (n.d.). Retrieved November 10, 2019, from http://www.fao.org/faoterm/collection/incident-command-system/en/.

FEMA. 2017. *National Incident Management System (NIMS)*.

Gude, Patricia H., Kingsford Jones, Ray Rasker, & Mark C. Greenwood. 2013. "Evidence for the Effect of Homes on Wildfire Suppression Costs." *International Journal of Wildland Fire* 22(4):537–48.

Gude, Patricia, Ray Rasker, & Jeff van den Noort. 2008. "Potential for Future Development on Fire-Prone Lands." *Journal of Forestry* 106(4):198–205.

Hand, Michael, Hari Katuwal, David E. Calkin, & Matthew P. Thompson. 2017. "The Influence of Incident Management Teams on the Deployment of Wildfire Suppression Resources." *International Journal of Wildland Fire* 26(7):615–29.

Hannestad, Stephen E. 2005. "Incident Command System: A Developing National Standard of Incident Management in the U.S." *ISCRAM Conference* (April):10.

Harvey, Brian J., Daniel C. Donato, & Monica G. Turner. 2016. "Drivers and Trends in Landscape Patterns of Stand-Replacing Fire in Forests of the US Northern Rocky Mountains (1984–2010)." *Landscape Ecology* 31(10):2367–83.

Holsinger, Lisa, Sean A. Parks, & Carol Miller. 2016. "Weather, Fuels, and Topography Impede Wildland Fire Spread in Western US Landscapes." *Forest Ecology and Management* 380:59–69.

Ingalsbee, Timothy. 2017. "Whither the Paradigm Shift? Large Wildland Fires and the Wildfire Paradox Offer Opportunities for a New Paradigm of Ecological Fire Management." *International Journal of Wildland Fire* 26(7):557–61.

Ingalsbee, Timothy & Urooj Raja. 2015. *The Rising Costs of Wildfire Suppression and the Case for Ecological Fire Use*. Elsevier Inc.

Jensen, Jessica & William L. Waugh. 2014. "The United States' Experience with the Incident Command System: What We Think We Know and What We Need to Know More About." *Journal of Contingencies and Crisis Management* 22(1):5–17.

Kasischke, Eric S., David Williams, & Donald Barry. 2002. "Analysis of the Patterns of Large Fires in the Boreal Forest Region of Alaska." *International Journal of Wildland Fire* 11(2):131–44.

Kramer, Heather Anu, Miranda H. Mockrin, Patricia M. Alexandre, & Volker C. Radeloff. 2019. "High Wildfire Damage in Interface Communities in California." *International Journal of Wildland Fire* (Obama 2016):641–50.

Lampin-Maillet, Corinne, Marielle Jappiot, Marlène Long, Christophe Bouillon, Denis Morge, and Jean Paul Ferrier. 2010. "Mapping Wildland-Urban Interfaces at Large Scales Integrating Housing Density and Vegetation Aggregation for Fire Prevention in the South of France." *Journal of Environmental Management* 91(3):732–41.

Lloret, Francisco, Eduard Calvo, Xavier Pons, and Ricardo Díaz-Delgado. 2002. "Wildfires and Landscape Patterns in the Eastern Iberian Peninsula." *Landscape*

Ecology 17(8):745–59.

Lotan, James E. 1979. “Integrating Fire Management into Land-Use Planning: A Multiple-Use Management Research, Development, and Applications Program.” *Environmental Management* 3(1):7–14.

Marlon, Jennifer R., Patrick J. Bartlein, Daniel G. Gavin, Colin J. Long, R. Scott Anderson, Christy E. Briles, Kendrick J. Brown, Daniele Colombaroli, Douglas J. Hallett, Mitchell J. Power, Elizabeth A. Scharf, and Megan K. Walsh. 2012. “Long-Term Perspective on Wildfires in the Western USA.” *Proceedings of the National Academy of Sciences of the United States of America* 109(9):E535-43.

Martin, Wade E., Ingrid M. Martin, and Brian Kent. 2009. “The Role of Risk Perceptions in the Risk Mitigation Process: The Case of Wildfire in High Risk Communities.” *Journal of Environmental Management* 91(2):489–98.

Moynihan, Donald P. 2009. “The Network Governance of Crisis Response: Case Studies of Incident Command Systems.” *Journal of Public Administration Research and Theory* 19(4):895–915.

NIFC. 2011. “ICS-209 When to Report Wildland Fire Incidents.” 1–7.

Paveglio, Travis B., Jesse Abrams, and Autumn Ellison. 2016. “Developing Fire Adapted Communities: The Importance of Interactions Among Elements of Local Context.” *Society and Natural Resources* 29(10).

Paveglio, Travis B., Matthew S. Carroll, Troy E. Hall, and Hannah Brenkert-Smith. 2015. “‘Put the Wet Stuff on the Hot Stuff’: The Legacy and Drivers of Conflict Surrounding Wildfire Suppression.” *Journal of Rural Studies* 41:72–81.

Radeloff, Volker C., David P. Helmers, H. Anu Kramer, Miranda H. Mockrin, Patricia M. Alexandre, Avi Bar-Massada, Van Butsic, Todd J. Hawbaker, Sebastián Martinuzzi, Alexandra D. Syphard, and Susan I. Stewart. 2018. “Rapid Growth of the US Wildland-Urban Interface Raises Wildfire Risk.” *Proceedings of the National Academy of Sciences* 115(13):3314–19.

Schoennagel, Tania, Thomas T. Veblen, and William H. Romme. 2004. “The Interaction of Fire, Fuels, and Climate across Rocky Mountain Forests.” *BioScience* 54(7):661.

Schwartz, Naomi B., Maria Uriarte, Victor H. Gutiérrez-Vélez, Walter Baethgen, Ruth DeFries, Katia Fernandes, and Miguel A. Pinedo-Vasquez. 2015. “Climate, Landowner Residency, and Land Cover Predict Local Scale Fire Activity in the Western Amazon.” *Global Environmental Change* 31:144–53.

Spies, T. A., E. White, A. Ager, J. D. Kline, J. P. Bolte, E. K. Platt, K. A. Olsen, R. J. Pabst, A. M. G. Barros, J. D. Bailey, S. Charnley, J. Koch, M. M. Steen-Adams, P. H. Singleton, J. Sulzman, C. Schwartz, and B. Csuti. 2017. “Using an Agent-Based Model to Examine Forest Management Outcomes in a Fire-Prone Landscape in

Oregon, USA." *Ecology and Society* 22(1).

Steelman, Toddi. 2016. "U . S . Wildfire Governance as Social-Ecological Problem." 21(4).

Steelman, Toddi A. and Caitlin A. Burke. 2007. "Is Wildfire Policy in the United States Sustainable?" *Journal of Forestry* (March):67–72.

Steelman, Toddi A. and Sarah M. McCaffrey. 2011. "What Is Limiting More Flexible Fire Management-Public or Agency Pressure?" *Journal of Forestry* 109(8):454–61.

Stephens, Scott L. and Lawrence W. Ruth. 2005. "Federal Forest-Fire Policy in the United States." *Ecological Applications* 15(2):532–42.

Stonesifer, Crystal S., David E. Calkin, and Michael S. Hand. 2017. "Federal Fire Managers' Perceptions of the Importance, Scarcity and Substitutability of Suppression Resources." *International Journal of Wildland Fire* 26(7):598–603.

Sturtevant, Brian R. and David T. Cleland. 2007. "Human and Biophysical Factors Influencing Modern Fire Disturbance in Northern Wisconsin." *International Journal of Wildland Fire* 16(4):398–413.

Syphard, Alexandra D. and Jon E. Keeley. 2015. "Location, Timing and Extent of Wildfire Vary by Cause of Ignition." *International Journal of Wildland Fire* 24(1):37–47.

Thompson, Matthew P. 2013. "Modeling Wildfire Incident Complexity Dynamics." *PLoS ONE* 8(5):1–10.

Thompson, Matthew P. 2014. "Social, Institutional, and Psychological Factors Affecting Wildfire Incident Decision Making." *Society and Natural Resources* 27(6):636–44.

Thompson, Matthew P., Francisco Y. Rodríguez Silva, David E. Calkin, and Michael S. Hand. 2017. "A Review of Challenges to Determining and Demonstrating Efficiency of Large Fire Management." *International Journal of Wildland Fire* 26(7):562–73.

Thompson, William A., Ilan Vertinsky, Hans Schreier, and Bruce A. Blackwell. 2000. "Using Forest Fire Hazard Modelling in Multiple Use Forest Management Planning." *Forest Ecology and Management* 134(1–3):163–76.

Turner, Monica G., William W. Hargrove, Robert H. Gardner, and William H. Romme. 1994. "Effects of Fire on Landscape Heterogeneity in Yellowstone National Park, Wyoming." *Journal of Vegetation Science* 5:731–42.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. "Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity." *Science* 313(5789):940–43.

Westerling, Anthony Le Roy. 2016. "Increasing Western US Forest Wildfire Activity: Sensitivity to Changes in the Timing of Spring." *Philosophical Transactions of the Royal Society B: Biological Sciences* 371(1696).

Williams, F. A. 1982. "Urban and Wildland Fire Phenomenology." *Progress in Energy and Combustion Science* 8(4):317–54.

APPENDIX A: SUPPLEMENTARY MATERIALS FOR CHAPTER 2

Interview questions

Q1.1 What are the most important goals during fire incidents?

Q1.2 Which documents provided to ICs or fire and/or forest managers do you find the most useful, and which do you feel like impede managers' ability to perform their duties to the fullest extent?

Q1.3 What are the most viable/feasible/effective management tools for responding to or achieving the goals for incidents?

Q1.4 Do you find that the 209 form for reporting incident information aligns with what is on the ground? Is it meaningful?

Q1.5 What is the point of reporting for you?

Q2.1 What landscape, management, or demographic factors currently impact suppression decisions in managing fires, and to what degree?

Q2.2 Under what conditions do you select suppression methods other than full suppression?

Q3.1 During a fire incident, when is suppression method likely to change?

Q3.2 In our preliminary data analysis, we've seen stronger relationships associated between specific suppression methods and the following (in no particular order): (1) IMT type and level (local, state, federal, mixed), (2) state, (3) "terrain" and (4) "fuels" (as defined by 209 form), (5) unit type (state, federal, interagency, private), and (6) national preparedness level. Can you comment on these relationships? Do you see them as strong connections?

Q3.3 Are there other variables (besides weather) that in your experience are closely related to suppression decisions?

Q3.4 Of the variables that impact suppression decisions, which do you feel you have the most and the least control over?

Q4.1 How well would you say that the suppression method types "maintain and monitor", "point zone", and "confine and contain" accurately account for what is happening on the ground?

Q4.2 Are the suppression method types "maintain and monitor", "point zone", and "confine and contain" more frequently or less frequently used together?

Q5.1 What future changes (e.g. drought, fire, insects, fragmentation) concern you the most for the region?

Q5.2 What future changes will most impact suppression decisions during fire incidents?

Q6.1 In the future, do you envision having more or less autonomy and capability to select suppression methods other than full suppression (i.e. "maintain and monitor", "point zone", or "confine and contain")?

Q6.2 In the future, what policies, both regional and national, or trends in agency dynamics do you see as necessary or precursors to utilizing suppression methods other than full suppression, given the right landscape/weather conditions?

Table A1. Variables with sources and relevant references

Independent Variable	References	Source
Report Date	(Westerling 2016)	209
Area (Log of)	(Littell et al. 2009)	Created from 209 Area
Duration	(Janie Canton-Thompson et al. 2008)	Created from 209 Start/ End Dates
National Preparedness Level	(Masarie et al. 2019)	IMSR NIFC
Cause	(Syphard & Keeley 2015b)	209
IMT Rank	(Canton-Thompson et al. 2008)	Created from 209 IMT Type
Ownership State	("Montana Department of Natural Resources and Conservation Briefing Manual for Northwest Compact and Other Out-of-Geographic-Area Resources," n.d.)	209
Unit Type	("Montana Department of Natural Resources and Conservation Briefing Manual for Northwest Compact and Other Out-of-Geographic-Area Resources," n.d.)	209
Injuries to Date	(Janie Canton-Thompson et al. 2008)	209
Primary Fuel Model	(Holsinger, Parks, & Miller 2016; Harvey, Donato, & Turner 2016b)	209
Primary Land Cover Class	(Holsinger, Parks, & Miller 2016; Harvey, Donato, & Turner 2016b)	Created (based on NLCD classes)
Easement	(Byrd, Rissman, & Merenlender 2009)	NCED
Aspect	(Baker, Veblen, & Sherriff 2007; Kasischke, Williams, & Barry 2002)	USGS
Terrain		209
Growth Potential		209
Elevation	(Alexandre et al. 2016; Baker, Veblen, & Sherriff 2007)	NCDC
Temperature	(Williams 1982)	NCDC
Relative Humidity	(Williams 1982)	NCDC
Distance to Road/Rail	(Cardille, Ventura, & Turner 2017)	TIGER/ LINE
Median Home Values		US Census

WUI Flag	(Radeloff et al. 2018; Kramer et al. 2019)	SILVIS
Seasonal Housing Unit Density	(Lampin-Maillet et al. 2010)	US Census

Table A2. Pearson correlation matrix of independent variables

	Latitude	Longitude	Report DOY	Fire Area	National Preparedness Level	Cause of Ignition	IMT Rank	Primary Fuel Model	Perceived Growth Potential	Terrain	Temperature	Relative Humidity	Elevation	Aspect	Distance to Road/Railroad	Median Home Value	Seasonal Housing Unit Density	Housing Unit Density	Primary Land Cover
Longitude	**-0.39***																		
Report DOY	**0.029***	**-0.04***																	
Fire Area	**-0.08***	**0.104***	**-0.21***																
National Preparedness Level	**-0.03***	-0.02	**-0.41***	**0.155***															
Cause of Ignition	**-0.06***	**0.080***	**-0.23***	**0.338***	**0.109***														
IMT Rank	**0.063***	0.020	**0.233***	**-0.31***	**-0.29***	**-0.14***													
Primary Fuel Model	**0.111***	**-0.04***	**-0.08***	**-0.03***	0.003	**0.109***	**0.045***												
Perceived Growth Potential	-0.02	-0.02	**-0.03***	**-0.13***	**0.060***	**-0.12***	**-0.08***	-0.02											
Terrain	**0.114***	**-0.14***	**0.041***	**-0.11***	-0.01	**-0.15***	-0.00	**-0.03***	**0.526***										
Temperature	**0.069***	**-0.08***	**-0.04***	0.018	**-0.03***	-0.00	**0.056***	**0.060***	0.011	0.018									
Relative Humidity	**0.119***	**-0.12***	**0.333***	**-0.24***	**-0.24***	**-0.18***	**0.243***	0.017	-0.01	**0.048***	0.005								
Elevation	**-0.34***	**0.232***	0.007	**0.045***	**0.067***	**-0.03***	**-0.09***	**-0.12***	**0.028***	**-0.05***	**-0.08***	**-0.05***							
Aspect	**0.078***	-0.01	**0.076***	**-0.05***	0.009	**-0.06***	**0.055***	-0.01	**0.043***	**0.044***	-0.01	**0.124***	**-0.03***						
Distance to Road/Railroad	0.000	**-0.13***	**0.068***	**-0.13***	0.001	**-0.17***	**0.029***	**-0.13***	**0.093***	**0.084***	**0.029***	**0.038***	**-0.03***	**-0.05***					
Median Home Value	**-0.38***	**0.404***	-0.00	**0.054***	-0.00	**0.098***	**-0.06***	-0.00	**-0.04***	**-0.10***	**-0.08***	**-0.08***	**0.156***	**-0.05***	-0.01				
Seasonal Housing Unit Density	**0.031***	**-0.03***	**-0.11***	-0.00	**0.053***	**0.205***	**-0.04***	**0.045***	**-0.09***	**-0.02***	0.017	**-0.04***	**-0.09***	**-0.10***	0.025	**0.086***			
Housing Unit Density	**0.099***	**-0.04***	**-0.16***	**0.133***	**0.088***	**0.223***	**-0.06***	**0.040***	**-0.07***	**-0.05***	-0.00	**-0.08***	-0.00	-0.01	**-0.15***	0.008	**0.156***		
Primary Land Cover	**-0.26***	**0.137***	**-0.09***	**0.219***	**0.082***	**0.124***	**-0.03***	**0.067***	-0.01	-0.01	-0.00	**-0.07***	**-0.06***	**0.066***	**-0.04***	**0.144***	-0.00	-0.02	

Unit Type (Federal/Not Federal)	**-0.13***	0.015	**0.144***	**-0.25***	**-0.14***	**-0.36***	**0.161***	**-0.15***	**0.122***	**0.116***	**-0.03***	**0.099***	**0.253***	**-0.12***	**0.187***	**-0.02***	**-0.14***	**-0.26***	**-0.18***

APPENDIX B: CHANGES IN SUPPRESSION METHOD

For most fire incidents for which suppression method has been recorded, the suppression method reported did not change during the incident. However, 39 incidents in the data reported a change in suppression method. A closer look at these fires provides additional context for factors influencing IC decisions regarding suppression methods. In particular, the additional variables included in this analysis (listed below) provide this context from the perspective of ICs, because these variables are created based on qualitative information provided by ICs in the 209s. In the case of fires in which the suppression method changed during the incident, how did management and socioeconomic contexts, in addition to environmental and fire behavior variables, influence fire managers' decision to change the suppression type? To address this question, I conducted an ordinal regression analysis and paired it with interviews with key informants and incident commanders (ICs). This mixed methods approach mirrors the larger study conducted and included as chapter two of this thesis.

A more detailed regression analysis was conducted to answer this research question regarding factors that influence ICs' decision to change suppression methods. The detailed analysis includes the incidents during which the suppression method reported changed. Our dataset included 39 such incidents (see Table B1) with 11 incidents listed as complex fires (multiple fires happening at different locations managed within one reporting channel). As complex fires do not fully address the question of suppression method changing during the incident, they were removed. I then turned to the remaining incidents with changes in suppression (n = 28), selecting incidents that include qualitative information (n=19), to determine which of our variables had the most significant effects on the decision to change suppression method. Selecting these incidents provided opportunities to utilize the context for suppression method change as described by ICs, as opposed to external data.

Table B1. Incidents that Reported Suppression Method Changes

Incident Name	Secondary Suppression	In Suppression Change Regression
Incidents starting with full suppression		
Birthday	confine and contain	Yes
Burroughs	confine and contain	Yes
Index Creek	confine and contain	Yes
Little Queens	confine and contain	Yes
Siegel Fire	confine and contain	Yes
Thunder City	confine and contain	Yes
Ballinger	point zone protection	Yes
Banner	point zone protection	Yes
Elbow Pass Complex	point zone protection	No (complex)
Goblin Gulch	point zone protection	Yes
Halstead	point zone protection	Yes
Millie	point zone protection	Yes
Pine Creek	point zone protection	Yes
Prisoner Lake	point zone protection	Yes
Sawtooth	point zone protection	Yes
Incidents starting with confine and contain		
Miner Paradise Complex	full suppression	No (complex)
Siegel Fire	full suppression	Yes
Whitehawk Complex	full suppression	No (complex)
Bearpaw Bay	point zone protection	Yes
Bighorn	point zone protection	Yes
Forty One Complex	point zone protection	No (complex)
Kootenai Creek	point zone protection	Yes
Saddle Complex	point zone protection	No (complex)
Incidents starting with point zone protection		
Bielenburg	confine and contain	Yes
Bull	confine and contain	Yes
Cardinal Creek	confine and contain	Yes
Ninko Creek	confine and contain	Yes
Stewart Fire	confine and contain	Yes

Line Fire	full suppression	Yes
Little People	full suppression	Yes
Isabella Complex	maintain and monitor	No (complex)
Mustang Complex	maintain and monitor	No (complex)
Skull	maintain and monitor	Yes
Incidents starting with maintain and monitor		
Alpine Lake	confine and contain	Yes
Bear Cub	confine and contain	Yes
Kendall	confine and contain	Yes
Mission Falls	confine and contain	No (<100 acres)
Cygnet Complex	point zone protection	No (complex)
Gold Pan Complex	point zone protection	No (complex)

Table A2. Counts of suppression change: There were 50 occurrences of suppression change among the subset of 39 incidents. Tallies within the table may count incidents more than once if suppression method changed multiple times or if the incident was part of a complex

To

From

	FS	PZ	CC	MM	Row Sum
FS		10	8	0	18
PZ	2		4	4	10
CC	4	8		1	13
MM	1	4	4		9
Column Sum	7	22	16	5	

Methods

For the regression analysis of fire incidents during which suppression method changed, the ordinal outcome variable is the difference in suppression method from the previous day (range = -2:3). Using the created response variable for the difference in suppression from the day before, changes in independent variables were evaluated for a potential role in the change in suppression method.

For most of the independent variables, I created a Yes/No flag for the following key words to search within qualitative information in the 209s: “red flag”, “habitat”, “resource objective*”, “structure*”, “fire growth”, “values at risk”, “limited resources”, “precipitat*”, “rain*”, “terrain”, “recreation*”, and “WFDSS”. The qualitative information from the 209 data comes from ten columns: Major Problems, Remarks, GACC Remarks, Observed Fire Behavior, Significant Event, Planned Actions, Projected Movement, Projected Movement (24 hours), GACC Significant Event, and GACC Observed Fire Behavior.

The remaining independent variables were also from the 209s. These included fire size (created from the natural log of fire area), IMT rank (created from IMT type), perceived growth potential, and terrain.

Results

Fire size was negatively associated with a change to increased suppression, indicating a smaller fire size was more associated with an increase in suppression. Terrain was positively associated with a change to increased suppression, indicating the more extreme terrain was, the more likely the change in suppression would be toward full suppression.

Of the variables added based on key word flags, language in the qualitative information columns related to fire growth and habitat had significant, negative associations with a change to increased suppression. In the qualitative data, “fire growth” was used with “limited” or “monitoring” or “minimal for all but one instance, in which it was used with “of approximately 150 acres”. The negative association of “fire growth” with increased suppression does not support my original hypothesis. The use of “habitat” in the qualitative data was exclusive to wildlife habitat and the positive association with increased suppression confirmed my hypothesis.

Language in the qualitative information columns mentioning “structure*” and “WFDSS” was positively associated with an increase in suppression method at the $p<0.10$ level. The positive association between “structure*” and increased suppression confirmed my hypothesis, but the positive association between “WFDSS” and increased suppression did not. The use of “structure*” in the qualitative data was used with “protection”, “triage”, and “historic”.

Interview Responses

In regards to factors that cause ICs to change suppression methods during an incident, the interviewees listed fire behavior (n = 4), fuels (n = 3), values at risk (n = 3), weather (n = 2), time of year (n = 2), and resource availability (n = 1).

Interviewees mentioned the importance of fire moving across the landscape, relating to fire size and perceived growth potential in the regression, on the decision to change suppression methods:

> *If you have a fire that’s moving from a federal jurisdiction where the fire may have initially been kind of a confine and contain or maintain and monitor, and it moves out of that realm to an area in which you have higher values at risk and potential for moving across to other jurisdiction, you need then to look at shifting your strategy to a more indirect/direct suppression strategy* (Interview #8).

Interviewees highlighted the limitations in what gets reported in 209s: "It might be doing great for mule deer habitat, they can't claim that, but they can say that they can't fight the fire up there because they can't fight it safely." (Interview #4).

Case Studies: When Suppression Changes; Pine Creek and Halstead Fires

Looking more closely at two fires during which suppression methods changed, we see the effects shown in analyses reported in this thesis. Pine Creek and Halstead were both discussed in interviews with relevant ICs, and were fires that highlight the importance of the factors included in this study.

The Pine Creek fire took place between August 29 and November 19, 2012 in Park County, Montana, nine miles south of Livingston, Montana. As reported in the 209s, the Pine Creek fire occurred on land owned and/or managed by the Montana Department of Natural Resources. It was caused by human ignition, had a maximum fire area of 12,000 acres, and was managed initially as full suppression, switching to point-zone protection on the 15th day of reporting, September 12th. The initial IC was a type 3 IC, but on August 31st, a type 1 IMT took over for nine days, after which a type 3 IC was reinstated, switching to a type 4 IC on October 4th. After the switch back to the type 3 IC, the reporting shifted from daily to every 3-7 days. On September 4th, two injuries were noted on the 209: "A fire fighter was sent to the hospital yesterday with a deep bruise leg injury and one camp personnel went to the hospital with an eye injury".

Mentioned in Major Problems is the WUI and private structures, in addition to extreme terrain. Early in the fire, extreme weather conditions and terrain were reported with large increases in fire size and extreme fire behavior, coinciding with reports of lack of available resources. On the day before the change in suppression method, a red flag warning was in effect, and steep, inaccessible terrain was reported. On the day of suppression method change and in the reports following, no private structures were listed as threatened. This is linked with the Remarks section information on the day of suppression method change: “When the fire was converted to a Type 3 organization, it was transferred to a new incident number of MT-GNF-162 called the Pine Creek GNF fire. This is to reflect the incident managing the federal ownership, not any private land…”.

In interviewing an IC from this incident, many of the variables listed in the 209s were mentioned as critical factors in the decision to change suppression method:

> *Pine Creek is very different, because it started on state protection on private land and quickly burned through that little community of Pine Creek and then up into Forest Service land … even though we were happy calling that a full suppression fire, … because that fire was burning up into the wilderness and was going to run into the old Jungle Fire, from a standpoint of firefighter safety, cost, resource availability, and the fact that it was allowing fire to take its natural role in the wilderness, all of those things combined, we were like, ‘Yeah, we’re not going to go after it when it gets up into that country.'* (Interview #9).

Based on information from interviewees, the State of Montana allows for little deviation away from full suppression. Interviewee #9 discusses changing the suppression method utilized based on extreme terrain, safety, cost, resource availability, and fire as a natural role on the landscape.

The Halstead fire began on July 30, 2012 18 miles northwest of Stanley, Idaho and lasted 83 days. The reporting of this fire began on the third day of the incident. It was managed initially with a full suppression method but on the 15th day, the suppression method switched to point-zone protection. For the first two reports of the incident, a type

3 IMT managed it, but on the third report, the IMT switched to a type 1 team for 43 days. For the last 35 days, the incident was managed by a type 2 team, a type 3 team, then a type 4 IC. Four injuries were noted in the 209s, two of which were mentioned in the qualitative information; one injury was a twisted ankle, another a twisted knee.

The environmental conditions were described as extreme terrain for the first 48 reports and a primary fuel model 10, timber litter fuel, providing conditions for greater fire intensity and more frequent crowning out, spotting, and torching of individual trees (Anderson 1982). The primary and secondary land cover classes for the 5km surrounding this fire were evergreen forest, barren, and shrub/scrub. The nearest road or railroad to the Halstead fire's origin was 302km away. The NPL ranged from 2 for the first 3 reports, to 3 for the next 11 reports, and maxed out at 4 for the next 20 days of the incident before tapering back down.

The Major Problems, Significant Events, and Remarks sections of the 209 data for this incident reveal several consequential situations or issues impacting the suppression efforts. First, on the day before the change from full suppression to point-zone protection, resources were diverted from the Halstead fire to nearby fires, including two helicopters. During the days leading up to the change in suppression, many resources working on the fire were listed as critical: "Loss of these resources may compromise the current strategy for the Halstead fire" (GACC Remarks, 10 August 2012). Although a type 1 team led the incident after just a few days into the incident, the NPL increased at the same time. The extreme terrain and hot, dry weather conditions (as reported in the Remarks) were relevant to the suppression efforts, as well.

In the GACC Remarks on the day of the change in suppression method, the reason for the change is quite clear: “Strategy was modified from Full Suppression to Point Zone Protection: "Values driven suppression strategy with limited perimeter control utilizing a mix of direct, indirect, and point protection tactics and where there is a high probability of success and firefighter exposure is commensurate with the identified value at risk”” (GACC Remarks, 14 August 2012).

Speaking with an IC from this incident, the context surrounding the decision to change suppression becomes even clearer: “We never worked with more than 350 resources at any given time on the Halstead Fire, yet it lasted for three months and 180-something-thousand acres and threatened a lot of high values at risk, and yet we managed it with low numbers of resources because they weren’t available at a high PL” (Interview #8).

With favorable conditions and more access to resources, the early efforts during the Halstead fire were met with optimism, but the conditions shifted:

> *Early on in the Halstead fire, we had an opportunity to take the fire on our terms, and that meant that we had fire weather and fuel conditions – fire behavior conditions – allowed for the fire to move through the landscape while we prepped indirect lines that we could utilize to burn off and hold the fire back to the national forest areas while protecting the high values at risk. What changed on us later on on the Halstead was the fire weather conditions as well as fuel availability, and topographic conditions that influenced the fire’s direction and behavior caused us to take a more direct suppression approach to the incident. So that was an example there of changing fire weather, changing fuel, and changing topographic conditions that influence the fire that caused it to move very quickly toward high values at risk, and forced us into more of a direct attack suppression strategy* (Interview #8)

The high values at risk mentioned by the interviewee include “Long term economical and environmental impacts to the Stanley Basin, Salmon River corridor” (Major Problems, 12 August 2012), a Boy Scout camp, several private properties, power lines, and several highway corridors, based on information in the 209s.

Conclusion

While the regression analysis sheds light on the context surrounding the decision to change suppression methods during a fire incident, it only considers information from one day of each fire incident. Including information from several days before and after the decision to change suppression method in the quantitative analysis would provide a more complete representation of the decision-making context. This gap in the research highlights the complexity of analyzing temporally auto-correlated data.

Interviewees mentioned the importance of WUI, private structures, jurisdiction, terrain, weather, firefighter safety resource availability, and the natural role of fire when considering suppression method changes.

Other variables may impact the decision greater than our ability to measure them. As mentioned in Interview #4, making the decision to select less-than-full suppression might be reported with qualitative information about the safety of the firefighters or the dangerous terrain. This delimited use of 209s hampers the ability for agency personnel to effectively evaluate the situation and poses challenges for adapting to situations in the future.

Table A4. Factors influencing changes in suppression method; dependent variable is the difference in suppression from the previous day

Independent Variable	Description	Hypothesis	Estimate (Δ Suppression = -2:3)	Interview Responses to Questions of Factors Included in Changes in Suppression Method
Fire Area (Log of)	Log of the fire area reported in 209	An increase in fire size will be associated with full suppression	-0.388**	“sometimes you might order a type 1 or type 2 team to manage a fire, but if the fire gets to a certain size, you know you’re not going to be able to do 100% suppression on it. So the fire itself will dictate what the suppression methods will be”
IMT Rank	Ranking of IC or IMT based on IMT_TYPE, organized based on position training requirements/incident complexity	The lowest and highest levels of IMTs/ICs will be associated with full suppression, the IMTs/ICs in between will not have strong associations	-0.308	"Type 1 teams are going to bring a lot of horsepower and they’re going to put the fire out. That’s what a type 1 team is, they bring firepower. Usually, you’re into where we’re burning houses down and you’re in that kind of social/political realm when it bumps up to that type 1 team."
Perceived Growth Potential	Potential for future fire growth estimated by officer completing the 209, ranging from low to extreme	Higher growth potential will be associated with full suppression	0.382	"It should probably change every time conditions change significantly. Those changes could be based on the fire growing, and its now in different locations with different values at risk, or it could change based on time of your fire season."
Terrain	Description of terrain, from low to extreme; includes steepness, difficulty to navigate	More extreme terrain will be associated with less-than-full suppression	0.764*	"fuels and terrain, they certainly go without saying that’s obviously going to influence your capabilities of suppression methods"
“red flag”	Any use in qualitative data of the words “red flag”	The use of “red flag” will be associated with increased suppression	-0.162	"the state of your fuels and the timing are huge."
“resource objective”	Any use in qualitative data of the words “resource objective”	The use of “resource objective” will be associated with less-than-full suppression	-1.429	“Federal agencies all have some version of land management plan or fire management plan that says here is what is appropriate in terms of how you’re going to manage large fires in this area. Some of those plans will say this area is appropriate for, again, resource objectives but under certain circumstances, like early in the season, fire indices are really high… you might choose to do a protection

				objective"
“habitat”	Any use in qualitative data of the word “habitat”	The use of “habitat” will be associated with increased suppression	-4.755**	“if a fire starts in the wilderness or the backcountry where a resource objective is deemed to be appropriate, and then it comes out... then it's at a large cost to the state"
“structure*”	Any use in qualitative data of words beginning in “structure*”	The use of words beginning with “structure*” will be associated with increased suppression	0.940^	“If we have a fire start that we don’t wish to put out, we want it to do it’s natural role, we buy that fire for a long time, until the point where it looks like the fire will likely move off of federal and move to private lands… we are not going to look at changing our strategy."
“fire growth”	Any use in qualitative data of the words “fire growth”	The use of “fire growth” will be associated with increased suppression	-2.561***	"most of the time, it’s due to fire movement, the fire moves toward values at risk, so the method or methods that are used usually shift to those that are full or perimeter segment suppression rather than just a point protection or monitoring type actions. Usually, it’s going from a less restrictive to more restrictive factors.”
“value* at risk”	Any use in qualitative data of the words “value* at risk”	The use of “value* at risk” will be associated with increased suppression	0.601	“mostly it’s the location and where the fire’s perimeter – what kind of the values at risk are being immediately threatened in the vicinity of the fire.”
“limited resources”	Any use in qualitative data of the words “limited resources”	The use of “limited resources” will be associated with less-than-full suppression	2.770	"the reality is, we are more often backing off now to good places to fight the fire because we are limited in resources.”
“precipitat*”	Any use in qualitative data of words beginning in “precipitat*”	The use of words beginning in “preciptat*” or “rain*” will be associated with less-than-full suppression	-0.512	“It’s going to be weather or fuel type that’s going to change that” “The weather extremes we go through are becoming more significant.”
“rain*”	Any use in qualitative data of words beginning in “rain*”		-0.391	
“terrain”	Any use in qualitative data of the word “terrain”	The use of “terrain” will be associated with less-than-full suppression	0.644	"fuels and terrain, they certainly go without saying that’s obviously going to influence your capabilities of suppression methods"
“recreation”	Any use in qualitative data of the word “recreation”	The use of “recreation” will be associated with increased suppression	0.252	“Whether we put a fire out or not really becomes a question of is this a fire that we have confidence in that it will not impact resources outside of wilderness; At some point we look at public access, recreational use of the wilderness, as that being a part of our management decision, but that comes down quite a ways lower."
“WFDSS”	Any use in qualitative data of the abbreviation WFDSS	The use of “WFDSS” will be used with less-than-full	3.016^	“within that Wildland Fire Decision Support System you have all the different information that’s been communicated

		suppression		by the Forest … all the different management criteria and landscape classes, demographic information, all that is going to be in there as far as what the concerns, conditions, and expectations, authorizations would be for managing fire across that landscape. So I draw upon that very heavily so that's why I mentioned that earlier as one of those tools."

APPENDIX C: THE FUTURE OF SUPPRESSION DECISION-MAKING

This study's main focus is investigating management and socioeconomic factors that influenced suppression method decisions during fire incidents between 2008 and 2013; however, the results of the investigation support future outlooks and recommendations for future changes in fire policy. A remaining question of the study is: what changes would allow incident commanders (ICs) to feel enabled to select less than full suppression methods in the future? To answer this question, I included four questions addressing future changes and outlooks in interviews with eleven key informants and ICs.

Results and Discussion

Interviewees were asked to consider the necessary precursors for more autonomy in the future to select less-than-full suppression, given the right conditions. The interviewees identified: improved fuels management, increased risk tolerance, improved land management, decreased liability and/or increased agency support of line officer decisions, public support, agency leadership acknowledgement of the value of fire on the landscape, positive reinforcement of reporting less-than-full suppression, increased risk management training, perception of fire as natural, individual comfort with decision-making, redefining the nomenclature of 'suppression' and 'managing a fire'. Of those listed, risk tolerance was referenced most by interviewees (n = 4).

Interviewees highlighted resiliency and adaptability, through community efforts and policy endeavors: "Until we have more fire resilient communities, we will not have room much room there to change suppression" (Interview #7); "There has to be a shift in the agency where the being able to accept the risk and potential consequences will not…

you need to teach and through policy direction the line officer to be less liable for a making a decision that goes back" (Interview #6). Community or individual landowner actions influence ICs' outlooks on future decision space: "People chose to live here, and they have the ability to make their properties more fire safe, and they can, based on all of their choices, they get to live with the consequences, I'm really reluctant to put firefighters in harm's way because actions landowners have chosen not to take" (Interview #9).

The way ICs report suppression methods and the agencies' response to their methods heavily impacts the outlook interviewees had on future autonomy to select less-than-full suppression. In particular, several interviewees mentioned the benefit of incentivizing "positive reporting" – reporting suppression method decisions based on landscape conditions, resource objectives, values at risk, and the benefit to having the fire on the landscape. Taking away that positive reporting is "a substantial stumbling block" (Interview #4). Instead, it encourages "false positives": "the safety card is used a lot to manage fire on the landscape and I think that it is a false positive. We're not getting the word out; we're just saying it's just not safe to put people in there" (Interview #11)

Interviewees look for a future in which they have increased decision space to "choose to do the right thing and not have to candy coat it, not say we're doing this for safety but we'll be able to say we're doing this because this is the right decision based on the landscape, based on the resources; we have values at risk but be able to talk about it openly" (Interview #4). Another interviewee noted, "You need to display to the line officers that you make a decision, it's a good decision but you get bad outcome, we're going to stand behind you… How do we make the line officer less liable if a prescribed fire goes bad?" (Interview #6). An interviewee described what could be done with reporting and the impact that would have:

> *It's the right thing to do on the landscape collectively, but there's no way to positively report that. I did the right thing by not putting this fire out; I should get a pat on the back. There's no pat on the back coming from a national target or national policy direction. If we could recognize the work and risk that it takes to do that, just as we recognize the work and risk to get a timber sale out, or to do a prescribed burn, then I think we would have a) better alignment in organization and funding and b) we would have line officers who are more willing to make those decisions on game day.* (Interview #4)

Climate change impacts fire behavior and fire seasons, which influences interviewees' outlooks on future decision-making. "I think [a factor influencing future suppression method decision-making] would be the uncertainty we face in a changing climate and not really understanding the impacts of what that might be in post-fire environments." (Interview #5).

Other interviewees include anthropogenic changes to the landscape as causes for increased complexity in fire management in the future: "[fires] just seem to be getting bigger, more costly, more damaging. I think that maybe speaks to that fragmentation… there's just more people living on the land" (Interview #9).

Three interviewees affirmed that fire management is already on its way toward increased IC autonomy during fire incidents; "The autonomy is there and I feel like even with the team that I'm on, when we're given some the full suppression areas, utilizing the science and our folks on the ground and their experience, we're able to make some really good decisions and find places where we can let fire take its natural role and not effect the WUI" (Interview #11).

Conclusion

Steps toward increased autonomy for ICs to select less-than-full suppression methods in the future require changes in federal policy and public perception. Some changes are underway, and the effects are seen by select ICs in this study. If there were more agency recognition of the risk and work it takes to select less-than-full suppression methods, then we would see more ICs encouraged to make that selection.